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Using "space-time of action" to assess changes in accessibility: the example of Bogotá between 1993 and 2009

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EDITOR'S NOTE

This article is the translation of: Mesurer l'évolution de l'accessibilité à l'aide des "espaces-temps d'action" : l'exemple de Bogotá entre 1993 et 2009

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1. Introduction: analysis of household trips and joint changes in mobility practices due to urban change

- 1 Many studies in environmental psychology, sociology, demography, and geography have demonstrated the benefits of studying jointly the mobility of household members. Their daily trips start from their shared place of residence, whose location influences the mobility practices of each member. Some may benefit to the detriment of others in terms of daily travel distance or time, in so far as the times and modes of transport of each individual tend to influence those of the others (Hägerstrand, 1970; Pratt, Hanson, 1991; Singell, Lillydahl, 1986; Aguilera *et al.*, 2010). For France, mention may be made of the work by Berger and Beaucire (2002) on trade-offs regarding residential mobility and commutes within households in the Ile-de-France, and work by Jouffe *et al.* (2015) on the plans and tactics of poor households on the outskirts of Paris for coping with

mobility inequalities. Equally, Massot and Proulhac (2010) have examined the link between the lifestyle and mobility of working adults in Ile-de-France. In Latin America, Pérez López and Capron (2018) have studied arrangements and negotiations over car use in families in Mexico. Gouëset *et al.* (2014, 289-293) have examined how co-resident spouses in Bogotá combine their commutes as a function of their income, together with the combination of their modes of transport.

- 2 Still focusing on the family unit, other scholars have analyzed the joint daily mobility of parents and their children, the latter being economically dependent on the former and reliant on where they reside. Depending on the age of the children studied, scholars have analyzed the spatiotemporal interdependence of trips by adults and children, or, on the contrary, the extent to which children's trips are independent of those of their parents (Depeau, Ramadier, 2005), both for daily commutes (McDonald, 2008; Tigar McLaren, 2018; Fyhri *et al.*, 2011) and for journeys made during free time or for leisure activities (Depeau *et al.*, 2017). In many countries, such as in France with its system of school zoning, primary and secondary school children tend to travel a short distance from their place of residence. But the situation of students dwelling with their parents is visibly different, since the fact that there are fewer places of further education can result in far longer journeys. To apprehend these joint mobilities and resultant family arrangements, sophisticated data collection procedures have been developed. One instance of this is the procedure developed in France for the ANR MOBI'KIDS research program (Depeau *et al.*, 2019),¹ relating specifically to children in their final year at primary school or first year at secondary school.
- 3 The variables selected for these studies tend to be distance (either Euclidian or via a network), travel time, mode of travel, frequency of trip by purpose, income or social position, level of education, gender, and age. It may be noted that these works tend not to analyze or map the spatial location of daily itineraries by co-resident individuals, with the exception of that by Depeau *et al.* (2017). Furthermore, with only a few exceptions (Aguiléra *et al.*, 2010; Berger, Beaucire, 2002; Fyhri *et al.*, 2011), these studies tend to examine joint mobility practices at a given point in time, thus precluding examination of how they change over the course of one or two decades. Lastly, they do not analyze how daily trips or the destinations of individuals residing in the same space and time may evolve, even though rapid changes may occur, impacting directly on household mobility practices. One such change is alterations to demographic structure, such as the ageing of the population. Equally, household composition has changed over time, with single-parent families and dual-income couples now being more numerous. Changes also stem from urban transformation linked, for example, to shifts in areas of employment or education, alterations to the transport system, the spread or densification of the urban fabric, and so on and so forth.
- 4 Hence this article adopts a twin approach, both diachronic and spatial, to explore reconfigurations in the daily mobility of coresident adults and children. To this end, it draws on the concept of action space, supplemented by travel time, which provides a way of gauging one aspect of individuals' access to urban space. It sets out to ascertain whether adults are currently disadvantaged by residing in a location which is better suited to their children, or whether other factors are at work, depending particularly on the household's position in the social hierarchy. It also seeks to understand how mobility conditions have changed over time depending on where individuals reside in the city. Lastly, it studies whether joint adult/child mobilities have been systematically

reconfigured, or whether they have stabilized in the district under study. It is based on data about commutes by working adults and their co-resident children gathered at a sixteen-year interval in Bogotá, a Latin American city undergoing extensive transformation. The first survey was conducted in 1993 (the CEDE-ORSTOM research program),² and the second in 2009 (the ANR METAL program).³

- 5 The second section defines the concept of action space (AS), together with existing techniques for mapping these spaces, and introduces the concept of space-time of action (STA). Bogotá, the city for which STAs have been calculated, is presented in section 3. Section 4 details the material used, the population studied, and the method for calculating space-time of action. Results are discussed in section 5.

2. Theoretical considerations and analytical framework

2.1 The concept of "action space" and ways of mapping it

- 6 As noted in Dijst (1999), the concept of "action space" has been used in the human and social sciences since the 1930s (Von Dürckheim, 1932). The concept is found in studies about migration (Wolpert, 1965), in cognitive and behavioral studies (Höllhuber, 1974; Golledge, Stimson, 1997), and in those about daily or weekly mobilities (Dijst, 1999; Janelle, Goodchild, 1983; Noël *et al.*, 2001). Wolpert (1965) provides the following definition: "the individual's action space [...] is that part of the limited environment with which the individual has contact". This concept is inspired by that of life space as developed by Lewin (1951). As stated in Dijst (1999), "the spatial unit in which the activity spaces are located which have been visited by a person during some period of time is called the actual action space". Action spaces tend to be typified at the individual level (Schönfelder, Axhausen, 2002; Hirsch *et al.*, 2014; Jones, Pebley, 2014). The characteristics of individual action spaces (the number of places visited, the frequency of visits to each place, the distance from home, the size and shape of the action space, etc.) are then generally synthesized or else classified in accordance with a typology (Lord *et al.*, 2009; Hirsch *et al.*, 2014). Action spaces may also be defined at an aggregate level, in which case they refer to groups of individuals, in order to compare the places these groups frequent on a daily basis (Raine, 1978; Janelle, Goodchild, 1983; Buliung, Kanaroglou, 2006; Demoraes *et al.*, 2012; Demoraes *et al.*, 2016; Quiroga, 2014). It may also be noted that action spaces are sometimes used as an indicator of social exclusion or segregation (Jirón, 2009; Jirón 2010; Åslund, Skans, 2010; Palmer, 2013; Wang *et al.*, 2012; Jones, Pebley, 2014). As observed in Zhang *et al.* (2018), "people experience segregation not only in their residential places, but also in other places where they undertake daily activities, such as the workplace and sites for non-work activities". Thus a growing number of studies compare the spatial characteristics of activity spaces to assess segregation between social groups (Janelle, Goodchild, 1983; Schnell, Yoav, 2001; Schönfelder, Axhausen, 2003; Atkinson, Flint, 2004; Ellis *et al.*, 2004; Wong, Shaw, 2011; Järv *et al.*, 2015; Li, Wang, 2017; Demoraes *et al.*, forthcoming). To do so, scholars call on a wide variety of methodological approaches (general linear model, composite indices, regressions, location quotient, centrophonic analysis, exposure and dissimilarity measures, etc.). It may be noted that these articles do not systematically map action spaces. This may be attributable to the disciplines in which their authors

work (maps tend to be more frequent in studies by geographers), and also by the fact that the data tends to refer to the individual level, making it hard to synthesize on a map. Several scholars draw on aggregate data for spatial units (Ellis *et al.*, 2004; Wong, Shaw, 2011), and some studies do not provide any sort of map (Åslund, Skans, 2010; Atkinson, Flint, 2004; Li, Wang, 2017). The study zones are also highly variable, ranging from entire countries, to groups of cities, a single entire city, or several districts.

- 7 There are various ways of mapping action space. The choice of method is determined by the nature of the input data, depending on whether the spatial point pattern describes the daily trips with high spatial granularity (such as data based on mobile phone positions, travel logbooks, or GPS tracks) or not (geocoded destination places with no details about the itinerary). Drawing on logbooks of journeys over a six-week period in a German town in 1999, Schönfelder and Axhausen (2003) tests three methods for visualizing individual action spaces (confidence ellipses, kernel density estimates, and shortest path networks between places visited by an individual). Rai *et al.* (2007) uses four parametric geometries (ellipses, superellipses, Cassini ovals, and bean curves) to represent the spatial extent of all the places visited, while minimizing the area covered. These advanced methods were applied to journey logbooks and GPS tracks recorded over the space of several weeks in Finland and Denmark.⁴

2.2. From the concept of action space to that of “space-time of action”: an indicator of individuals’ access to activity places

- 8 As we have seen, comparing the places visited by different groups of individuals can bring out forms of exclusion or segregation. It also provides a way of emphasizing singular interactions between certain groups and specific sectors of the city (for example, the residents of dormitory towns may be captives of the center where jobs are concentrated in certain cities). From a diachronic perspective, comparing the action spaces from two different dates may also reveal changes in the functional dependence between the various parts of an urban area. Hence the shrinking of the action spaces of people living on the outskirts may result from these places maturing (with more local jobs and services, and greater local residential mobility), or conversely becoming marginalized (with deteriorating center-periphery transport services, congestion, excessive travel costs, etc.). With this in mind, it strikes us as essential to enrich the concept of action space if we wish to explore from a geographical perspective how individuals’ joint daily mobilities have been reconfigured. Action space is based on a set of places that an individual or group of individuals visit, primarily described using spatial metrics (distances, dispersal, or distance from home). But working solely with spatial metrics is far from satisfactory if we are to apprehend mobility phenomena, for they conceal many aspects of mobility conditions, particularly travel times. In Latin America, travel times are particularly linked to individuals’ sociodemographic characteristics, being longest for the most disadvantaged (Demoraes *et al.*, 2010), even though place-specific effects may alter this general tendency (Demoraes *et al.*, 2012).⁵ It is especially important to include the time of travel, for travel time may vary greatly for a given distance depending on the mode of transport, any connections needed (with it often be easier to travel from center to periphery than from periphery to periphery), as well as the availability of a rapid, mass public transport system near the place of residence. That is why we suggest a new concept that we call “space-time of action”, referring to all the destinations visited by individuals for work or study, together with

the time they take to reach them on a daily basis. What differentiates this approach from those described earlier, some of which nevertheless include a temporal dimension (travel time, time spent at each place, etc.), is that we include travel time directly in our calculation of space-time of action (section 4.3). Additionally, STAs may be mapped (sections 4.3 and 5) and not simply displayed in a table or analyzed through statistical modelling.

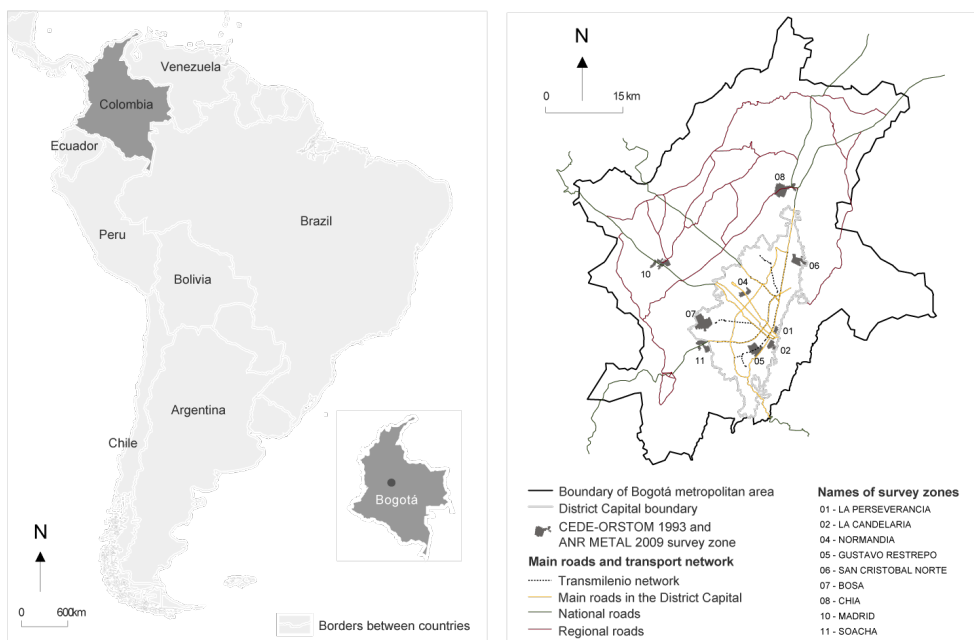
- 9 Furthermore, the concept of space-time of action has the advantage of broadly re-transcribing several dimensions of how individuals or groups of individuals access urban space. Indeed, following the definition put forward in Bavoux and Chapelon (2014), "four main components of accessibility may be identified: (1) the performance of the transport networks used and services delivered, expressed in terms of time, expenditure and/or effort, determining how easy or difficult the trip is; (2) the nature and spatial distribution of the resource to reach; (3) time constraints relating to social functioning (working hours, the time at which the school day starts and finishes, when shops open and shut, etc.); (4) the characteristics of the individuals prone to travel (age, physical aptitude, income, education etc.)". The concept of space-time of action includes the first component, for travel times account not only for distance from the destination but also for the performance of the mode of transport used, and indirectly the difficulty in travelling. It also includes the second component for it resumes the nature of the places to reach (work or study) and their spatial distribution. Travel times are also indicators of hours of work or study (the third component) in so far as, all other things being equal (the same mode of transport from the same point of departure to the same destination), the time spent travelling varies depending on whether it is rush hour or not. In the case of commutes, most take place at rush hour. Lastly, space-time of action can also be calculated for groups sharing the same characteristics (the fourth component) and so be compared. That is what we do in this article for the three sub-populations selected, namely co-resident working adults, schoolchildren, and students (section 4.2).

3. Presentation of the study area: Bogotá, a city undergoing transformation

- 10 Bogotá, the city used to test the operationality of STAs, is the capital of Columbia (map 1). It is a city undergoing extensive transformation due to the vigorous urban and demographic dynamics at work there (Dureau, Lulle *et al.*, 2014c), and to its having followed since the early 1990s globalized urban models, such as that of Barcelona (Montoya, 2014). The metropolitan area of Bogotá is composed of a very extensive city center, the "District Capital" (DC), subdivided into 20 *Localidades* or "localities", together with 19 suburban municipalities (map 2). The city center is heavily populated, with 4.9 and 6.7 million inhabitants respectively at the time of the last two available censuses (1993 and 2005), amounting respectively to 90% and 88% of the total metropolitan population. Nevertheless, demographic growth in the central localities of the District Capital (DC) has since slowed (map 2), with the highest growth rates now being in the outer localities of the DC, and especially in the municipalities outside the DC (Le Roux, 2015). Maps of the rates of demographic growth may be consulted in the METAL Maps collection available online.⁶

- 11 The process of urban sprawl, which has been well documented by various researchers (Montoya, 2012: 459; Salazar *et al.*, 2014: 83-108), is accompanied by socio-residential segregation, a classic process in Latin America, with the wealthier classes concentrated in the north-east of the District Capital, and the poorer classes relegated to the southern and north-western edges of the DC and to most of the suburban municipalities (Dureau, 2000; Salas, 2008; Demoraes *et al.*, 2011; Dureau, Contreras *et al.*, 2014a).⁷ These two processes of urban sprawl and segregation clearly have strong effects on mobility, particularly daily commutes (Moreno, 2016). Jobs are strongly spatially concentrated (map 3), in what has been described as a "polycentric" (Beuf, 2011; Le Roux, 2015) or "fragmented" (Alfonso, 2012) pattern, with job density generally tending to disadvantage the poorer localities and municipalities, even though the CEDE-ORSTOM 1993 and ANR METAL 2009 surveys go some way towards nuancing this general rule, as we shall see later.

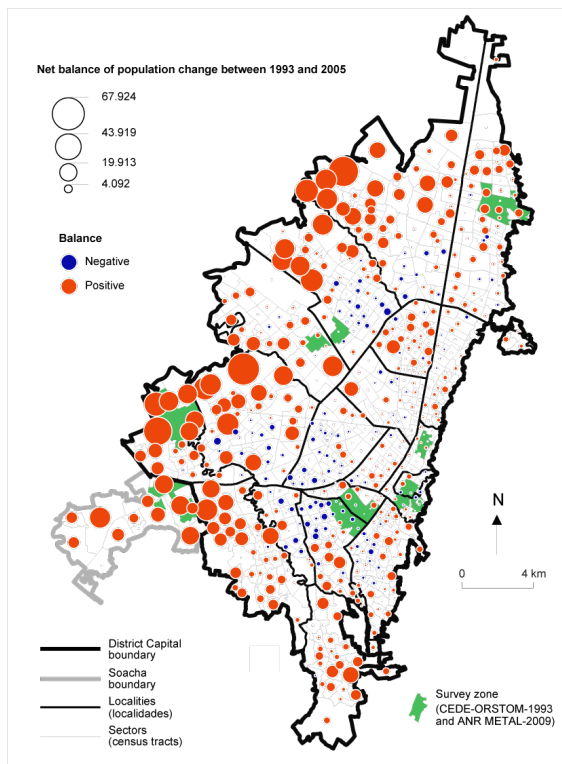
Map 1: The location of Bogotá, main roads, transport network, and location of the nine zones surveyed at both dates (1993 and 2009) in the metropolitan area



Left insert: author: F. Demoraes. Source: <https://gadm.org>

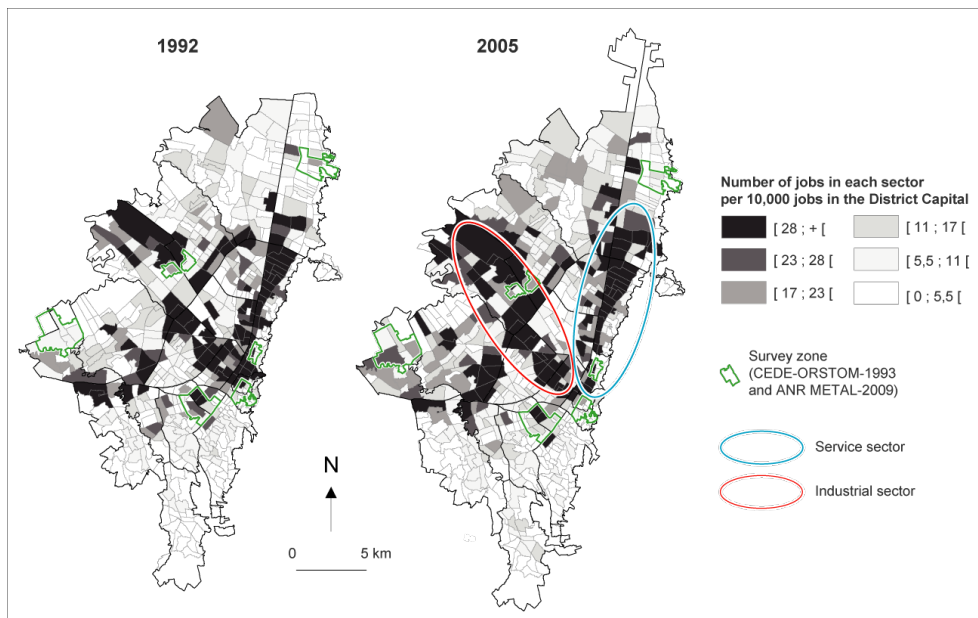
Right insert: author: G. Le Roux (2015: 129). Source: ANR METAL GIS database.

Map 2: Changes to Bogotá's population distribution between 1993 and 2009



Authors: F. Demoraes. Sources: DANE 1993, 2005. Data processing: A. Salas, ANR METAL

Map 3: Changes to the distribution of jobs in Bogotá between 1993 and 2009



Author: F. Demoraes, taken from G. Le Roux (2015: 129). Sources: for 1992, taken from F. Dureau (2000: 249); for 2005, taken from DANE 2005. Data processing: G. Le Roux

- 12 Concerning education, a broad distinction may be made between two different rationales, one pertaining to primary and secondary schools, the other to higher education. In the first case, public schools are uniformly distributed in space, while the

best reputed private schools are concentrated in the upmarket districts or suburban municipalities (particularly in Chía, see map 1). The universities are mainly concentrated in the city center and on the northern outskirts of Bogotá, with certain specific improvements between the two dates: while mid-quality technological and higher education courses became available in the poorer outskirts, more upmarket university courses developed in the wealthy localities of the capital and in the municipality of Chía.

- 13 Lastly, transport service provision is another important variable in changes to daily mobility in Bogotá. This is characterized by recent growth in household car ownership rates, which rose from 30% to 41% between 2005 and 2011,⁸ and the modernization of public transport with the development of a BRT system as of 2001,⁹ known as the *Transmilenio* (map 1). Broadly speaking, and as shown in Gouëset *et al.*, (2014), cars still tend to be the preserve of the wealthy, while poor people travel by bus, foot, bike, or motorbike. The only mode of transport used by all social classes in Bogotá in 2009 was the *Transmilenio*.

4. Material and method of analysis

4.1. Material used: two surveys for apprehending changes to spatial mobility in Bogotá between 1993 and 2009

- 14 Our analysis is based on two surveys conducted in Bogotá, devised in the wake of work by the GRAB research initiative,¹⁰ to apprehend individuals' spatial mobilities from a biographical perspective. The first of these was the 1993 CEDE-ORSTOM survey headed by Dureau and Flórez, in which 922 households and 3973 individuals were questioned; the second was the 2009 ANR-METAL survey, headed by Dureau, in which 881 households and 3256 individuals were questioned. Their purpose and methodology are detailed respectively in Dureau *et al.* (1994) and Dureau *et al.* (2011 et 2014b).¹¹ In these surveys, spatial mobility was studied in a global approach including all mobilities irrespective of distance (intra-urban travel or to the rest of the national territory or abroad) and travel time (ranging from daily trips to migrations). Nine survey zones were common to the two dates (map 1).
- 15 These zones constitute an illustrative mosaic of the range of socio-economic profiles, housing conditions, and urbanization phases in the Bogotá metropolitan area. They bring out the wide variety of daily mobility strategies households use. They also show highly contrasting levels of access to activity places. It should be noted that while the individuals surveyed at the two dates were statistically representative of their zone of residence, they were not so of the metropolitan area as a whole. It should also be noted that it was not a longitudinal survey, for the households surveyed in 1993 were not the same as those surveyed in 2009.
- 16 This article only uses one component of these two surveys, namely commutes from home to place of activity (place of work and place of study), collected in similar fashion at both dates. Given the purpose of the surveys (an overall understanding of all forms of mobility throughout the life cycle), and the quantity of information which may be gathered in a reasonable length of time using a questionnaire,¹² sequences within daily journeys were not recorded. We therefore do not have details about the routes through the city, only about one destination per day per individual recorded at the level of

sectors, which is a fairly fine-grained spatial level (there being 630 sectors in all in the Bogotá metropolitan area, map 2). In addition to destination, we also have data for both dates concerning mode of transport and travel time.

- 17 These surveys are precious sources of data without equivalent for Bogotá for the period under consideration. One of the limits to detailed study of daily mobility in Colombia, as in many Latin American countries, relates to the paucity of secondary sources, mainly origin-destination surveys and, to a lesser extent, population censuses. Origin-destination surveys provide overall knowledge about daily trips (their frequency and intensity) depending on age, gender, mode of transport, purpose, and travel time. They also provide information about household car ownership rates. These surveys present the advantage of being representative of the entire city and are conducted regularly, following a largely standardized methodology enabling diachronic analysis. However, in the case of Bogotá, the first major standardized OD survey dates from 2005. An earlier survey exists for 1996, financed by Japan, but it was devised using a specific methodology and sectorization precluding comparison with the 2005 survey. Furthermore, it is not possible to access individual data for the 1996 survey. The only available results are aggregated by sector, making it impossible to study jointly the mobilities of various household members. The CEDE-ORSTOM and METAL surveys are thus the only sources for analyzing the changing conditions in which commutes were conducted by Bogotá households during the 1990s and 2000s, a pivotal period characterized, as seen earlier, by the massive expansion in the number of private cars and the commissioning of the *Transmilenio*.

4.2. Selection of the study population

- 18 As indicated in the introduction, observing simultaneously the mobility of individuals at the household level is of major interest, for daily trips originate in the same dwelling whose location influences each members' mobility practices, and because mobility practices within a family unit are generally related to one another. This is particularly true of children's mobilities.
- 19 To meet our objective of understanding changes in how children and adults access their activity places, together with the forms of interdependence within families in managing their daily mobilities, we have selected surveyed households with at least one working individual (with a main or secondary paid activity, including at home) and at least one child in primary, secondary, or higher education (table 1). We have thus retained 49% of households surveyed in 1993, and 44% of those surveyed in 2009. We have dissociated students from primary and secondary school children, for higher education establishments are spread very unequally across the city, necessitating journeys following a specific rationale, as we shall see later (section 5).

Table 1: Distribution of households in Bogotá with at least one working adult and one child in education, by survey zone in 1993 and 2009 and by category of individual (working adults, schoolchildren, students).

SURVEY ZONE	Total number of households		Total number of individuals		Number of schoolchildren		Number of students		Number of working adults	
	1993	2009	1993	2009	1993	2009	1993	2009	1993	2009
Bosa	50	60	165	200	86	91	0	7	79	102
Chia	31	29	111	89	44	33	8	6	59	50
Gustavo Restrepo	56	55	206	178	90	65	16	19	100	94
La Candelaria	54	47	191	149	98	69	9	3	84	77
Perseverancia	46	22	152	64	73	26	6	3	73	35
Madrid	50	49	187	167	96	91	4	5	87	71
Normandia	51	34	205	103	61	20	42	25	102	58
San Cristobal Norte	66	40	244	122	126	51	11	10	107	61
Soacha	47	55	158	180	75	70	2	12	81	98
Overall total	451	391	1 619	1 252	749	516	98	90	772	646

Sources: CEDE-ORSTOM 1993 and ANR METAL 2009 surveys, Bogotá. Data processing: F. Demoraes. Reference population: individuals co-residing in households where at least one adult is in paid work (either at home or outside place of residence) and where at least one child is in education. NB: the numbers are of individuals with a known destination in the Bogotá metropolitan area.

4.3. Principle and method of calculating space-time of action

4.3.1. Space-time of action: origin and principle

- 20 The principle for calculating "space-time of action" (STA) is inspired by two sets of tried and tested methods, the first from the field of cartography, and the second from that of spatial analysis. However, as far as we know these two sets of methods have never been combined to study how individuals access their place of activity. The first set of methods, referred to in Cauvin (1997) and in Cauvin *et. al.* (2010) as "differential cartographic transformations of position", is used for comparisons. The second set of methods, called "centrographic analysis", provides a way of summarizing the position and dispersal of a point pattern.
- 21 The first set includes several algorithmic implementations. The earliest is bidimensional regression. This method issued from work by Tobler (1965, 1977) in the wake of research by d'Arcy Thompson. Differential cartographic transformations of position also include other subsequent methods with varying levels of nuancing (Boutoura, Livieratos, 1986; Spiekerman, Wegener, 1994; Langlois, Denain, 1996). The purpose of all these methods is to capture differences between positions. As observed in Bretagnolle (2007), the scale on temporal metric maps is expressed in terms of travel time from one place (unipolar cartogram) or between pairs of places (multipolar cartogram). In the example provided in Langlois and Denain (1996), the cartogram results from a unipolar differential cartographic transformation of position (the simplest case). It shows the time taken to travel by train from Paris to various stations in the surrounding regions, and opposite, the time taken to reach stations in the regions around London. In this example, there is only one duration per destination (the

time taken to travel by rail). Constructing multipolar cartograms is more complex and can engender problems in the topology of the distorted map.

- 22 Our case differs from these works in that we do not seek to distort space or to create cartograms based on travel time or cognitive distance. We have simply retained the idea of differential positions in space-time and taken the idea of equal speed put forward by Spiekerman and Wegener (1994), a parameter used as a benchmark for comparing actual distance-times to a hypothetical homogenous distance-time. Additionally, in the surveys we use, different travel times may be assigned to a single destination, either because individuals go there from different places, or because individuals departing from the same place of residence do not use the same mode of transport. It is thus a matter of retaining the times of individual trips for each destination, precisely so as to bring out any variations in how individuals access their activity place.
- 23 The second set of methods, centographic analysis, was formalized and popularized by Bachi (1963), building on work by Lefever (1926). We have chosen this because it can be used to produce standard deviational ellipses. Among the various possible mapping techniques presented in section 2.1 for visualizing and comparing action spaces, this method is particularly suited to the data we have, namely point patterns representing individuals' destinations. For unlike mobile phone positions, travel logbooks, and GPS tracks, these are not point patterns with a high spatial granularity which, as indicated in section 2.1, tend to be represented using network-based buffer zones or by itineraries tracing the shortest paths between the various places visited by an individual. Furthermore, an ellipse provides a good summary of the position of a point pattern around a mean or median center and portrays its dispersal. Another advantage of ellipses is that they offer a way of displaying several action spaces associated with different groups of individuals on a single map (in our case, six per survey zone, three for the adults, schoolchildren, and students in 1993, and three for the same groups in 2009). That is why the kernel method was not suitable, for it generates as many density maps as there are groups, and these maps must then be presented side-by-side to be compared. Additionally, ellipses are vector objects with associated metrics (size, standard distance, orientation, etc.), which can then be easily compared (section 5). Lastly, it should be noted that the method of minimum convex-hull polygons was rejected since it links the most excentric points without taking the distribution of the other points into account, which tends to exaggerate the size of action spaces.

4.3.2. Method for calculating STAs

- 24 To calculate the STAs for the two dates (1993 and 2009), we used location of place of residence (at the city block scale), location of place of activity (at the sector scale), and travel time. These three variables were processed using a series of GIS operations.¹³ This comprised three main stages: 1. Calculating distances and speeds 2. A series of translations 3. A series of centographic analyses. The variables presented in this and the following section are given in tables 4 and 5 (appended), taken from the overall dataset.

First part: calculating distances and speeds

- 25 **First stage:** calculating the Euclidean distance for each origin-destination pair in 1993 and in 2009, from centroid to centroid, and calculating average speed of travel for each pair.
- 26 **Second stage:** calculating overall average speed of travel for all the origin-destination pairs in 1993 and 2009. Since the objective was to define a synthetic measure of access to place of activity for each group of individuals, we did not break this down into speed by mode of transport.¹⁴ It should be noted that for our reference population, overall average speed did not change between 1993 and 2009 (10.8km/h).
- 27 **Third stage:** this average overall speed was used to calculate a "distance-time", corresponding to the distance an individual would have travelled in the length of time recorded for their actual journey had they been travelling at the overall average speed. This distance-time was calculated using the following formula:

$$\text{Distance Time} = \frac{\text{OD Euclidean distance m} * \text{Overall average speed m/min}}{\text{Speed m/min}}$$

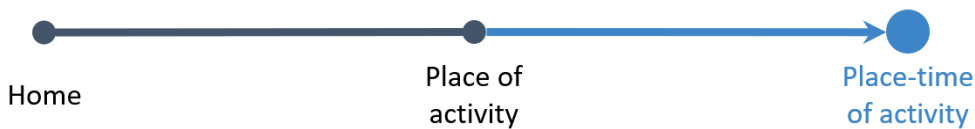
Second part: translation operations

- 28 Distance-time was used to calculate the location of "place-times of activity" (PTAs). These lay at different distances aligned with the initial origin-destination segment (maps 5 and 6). LTAs are shifted as follows:

- = nearer to home when the individual reaches the place more quickly, i.e. at greater speed than overall average speed,

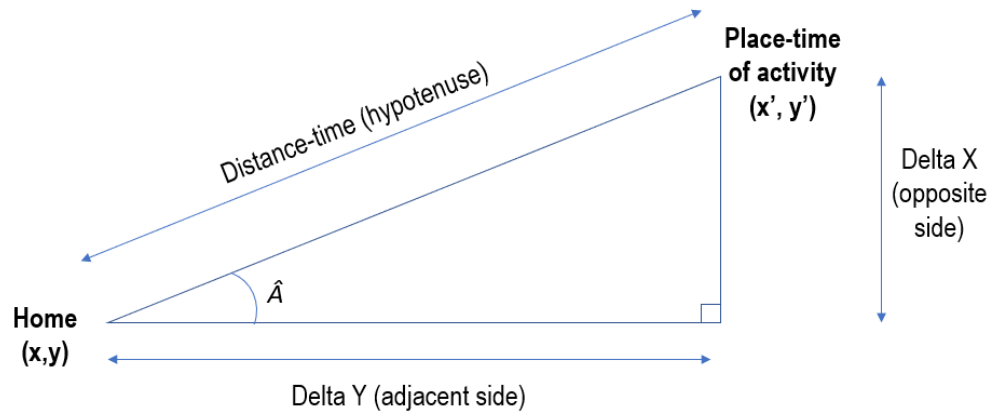


- = further from home when the individual reaches the place less quickly, i.e. at less than overall average speed.



- 29 The PTA coordinates (x' , y') were calculated by applying trigonometric principles. Distance-time corresponds to the length of the hypotenuse of a triangle with an apex corresponding to the centroid of the home block with coordinates x and y .¹⁵ Angle \hat{A} corresponds to the angle of the hypotenuse to a horizontal East-West axis also passing through the centroid of the home block (figure 1).

Figure 1: Applying the principles of trigonometry to calculating the coordinates of place-times of activity



- 30 To ascertain delta X and delta Y (expressed in meters), we initially converted the cosine and sine of orientation (expressed in degrees) into radians using the following formulae:

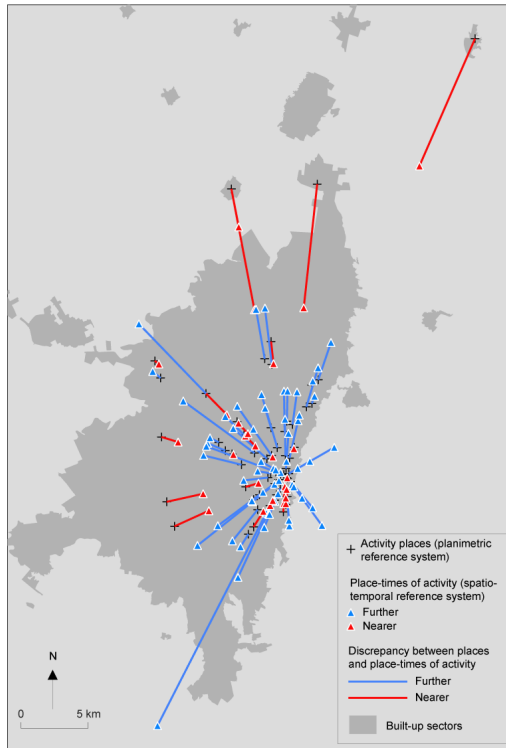
$$\text{Cosine } \hat{A} \text{ (radians)} = \frac{\text{Cos}(\text{Orientation}) \cdot \pi}{180} \quad \text{and} \quad \text{Sine } \hat{A} \text{ (radians)} = \frac{\text{Sin}(\text{Orientation}) \cdot \pi}{180}$$

- 31 We then used the sine and cosine of angle \hat{A} , as indicated in the following formula:

$$\text{Delta X} = \text{Distance Time} * \text{cosine } \hat{A} \quad \text{and} \quad \text{Delta Y} = \text{Distance Time} * \text{sine } \hat{A}$$

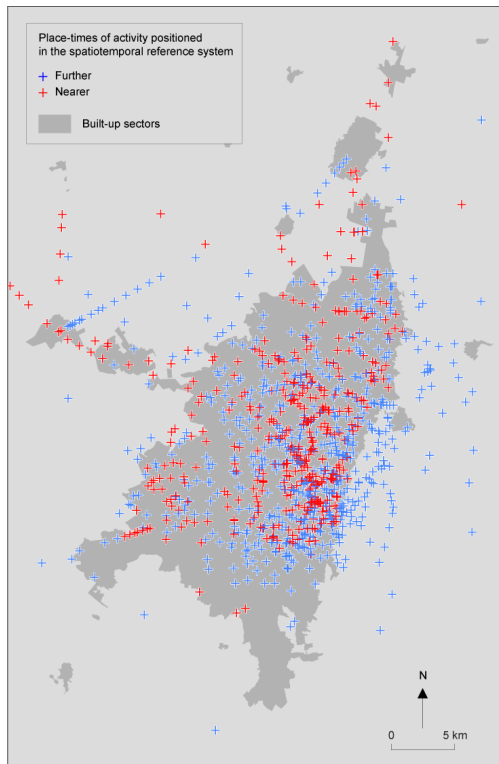
- 32 Lastly, to obtain the coordinates of the place-times of activity (x' , y'), we added respectively the value of delta X and delta Y (values which may be either positive or negative) to the coordinates x and y of the centroid of the respective home block. The values of x' and y' were recorded in the variables "X Proj PTA" and "Y Proj PTA". The operation applied to each individual thus corresponds to a series of translations whose origins correspond to the centroids of the blocks where individuals were surveyed. In 1993 there were 161 blocks in all, and 137 in 2009. The location of LTAs is thus not solely geographic since it includes a time dimension. PTAs are thus positioned in a new, spatiotemporal reference system. Map 4 shows the results of the operation for the Perseverancia survey zone. Map 5 shows the location of place-times of activity for all the individuals in the 9 survey zones in 2009.

Map 4: Comparison of activity places (in blue) and "place-times of activity" (in red), positioned respectively in planimetric and spatiotemporal reference systems corresponding to individuals residing in Perseverancia in 2009 (ANR METAL, Bogotá)



Author: F. Demoraes

Map 5: All "place-times of activity" positioned in the spatiotemporal reference system corresponding to individuals residing in the nine survey zones in 2009 (ANR METAL - Bogotá)

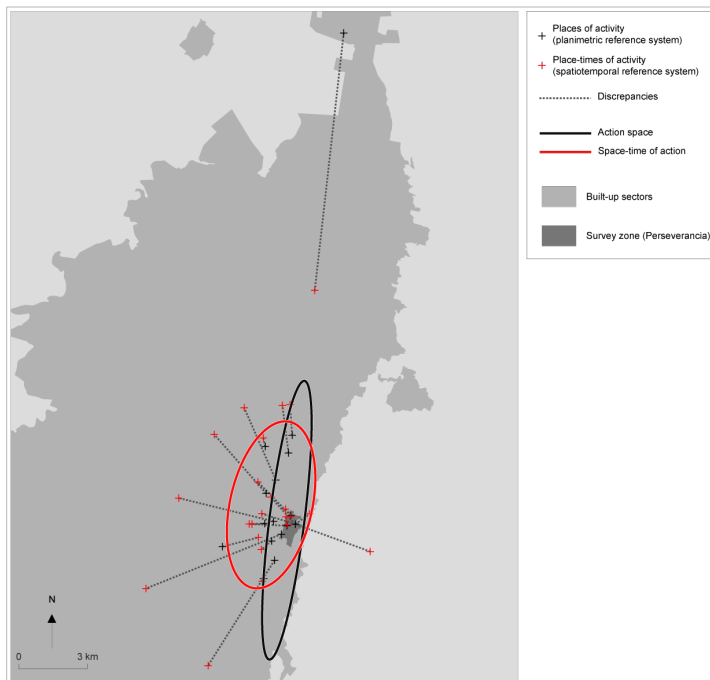


Author: F. Demoraes

Third part: centrographic analysis

- 33 As we had two point patterns (the first corresponding to all places of activity, the second to all place-times of activity), we applied centrographic analysis to each. This method can be applied to activity places to generate ellipses synthesizing the dispersal of destination places in space, thus providing a schematic map of action spaces (ASs). When applied to place-times of activity, it produces ellipses illustrating place-times of action (PTAs). An ellipse is characterized by several parameters (position, size, orientation, degree of flatness, etc.). In addition to mapping accessibility with ellipses, we also use the parameter of "standard distance" expressed in meters. This reflects the dispersal of destination places, supplemented for STAs with a temporal dimension. Ultimately, we have standard distances for both SAs and STAs, and we shall later see the interest in comparing them to describe activity place accessibility (figure 2). It should be noted that we chose the median point as the ellipse center, which is less sensitive to outliers (destination places far removed in time and/or space) than the mean point.
- 34 Map 6 illustrates how the two types of ellipse (SA and STA) are devised. In the study zone used here (Perseverancia), the SAs are extended along a north-south axis, whereas the STAs display a different pattern, which may be explained by slower travel speeds—hence lesser accessibility—westwards of the survey zone.

Map 6: Example of ellipses representing SAs and STAs of schoolchildren surveyed in Perseverancia, ANR METAL, Bogotá, 2009



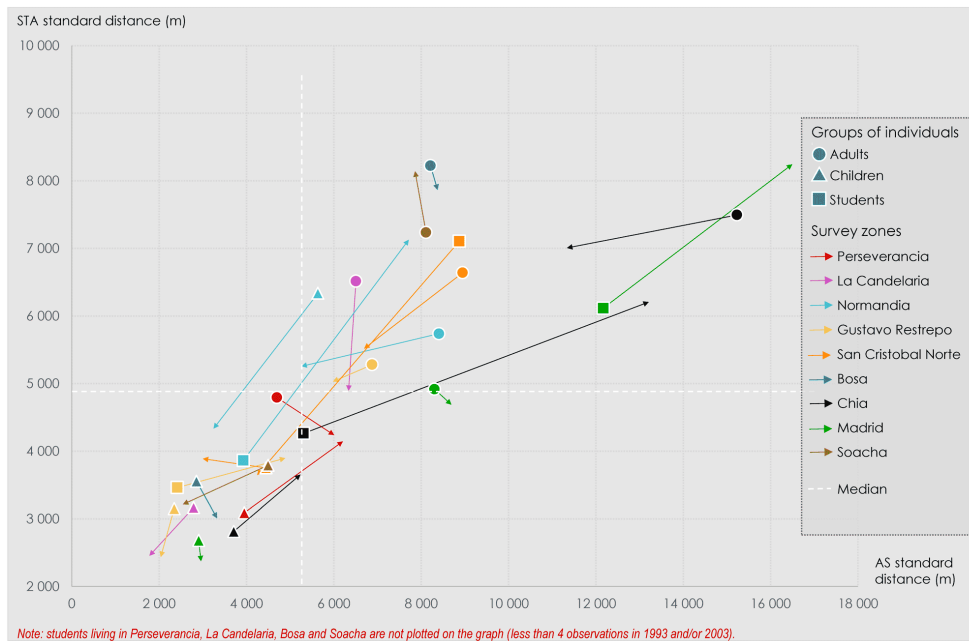
Author: F. Demoraes.

- 35 One ellipse was calculated per group. A group is a set of individuals residing in the same zone and with the same activity (in work, at primary or secondary school, or in further education). Ellipses were not traced for groups of less than four individuals. This was the case, for example, for students in the Bosa and Soacha survey zones in 1993. In all, 50 ellipses were calculated for all of the 9 zones surveyed at both dates.

5. Results

- 36 As we had comparable survey data available for both dates it was possible to measure changes in several parameters characterizing how household members accessed their place of activity in 1993 and 2009. Below we briefly present three illustrations (figure 2, table 2, and table 3) on which our results are based, before examining them in greater detail a bit further on. Based on AS (spatial dispersal of destinations) and STA (spatial dispersal of destination places including travel speeds) figure 2 synthesizes changes in access to place of activity between the two dates for each survey zone and for each of the three groups of individuals. Table 2 details changes in the distance from home to place of activity. Table 3 provides information about the modes of transport used by category of individuals and by survey zone for the two dates.

Figure 2: Changes between 1993 and 2009 in access from home to activity place for each of the nine survey zones and for each of the three groups of individuals



How to interpret the diagram: the more one moves to the top right, the more place of activity accessibility decreases (highly dispersed places, very long travel times).

Author: M. Bouquet. Sources: CEDE-ORSTOM 1993 and ANR METAL 2009 surveys - Bogotá. Data processing: F. Demoraes, M. Bouquet. Reference population: individuals co-residing in households with at least one adult in work and at least one child in education.

- 37 On figure 2, the x-axis represents standard distance measured for each ellipse in the planimetric reference system (ASs). The y-axis corresponds to standard distance measured for each ellipse in the spatiotemporal reference system (STAs). These latter standard distances reveal the dispersal of destinations supplemented by the temporal dimension. The symbols represent the values for each of the three categories of individual and for each of the nine survey zones. The arrows illustrate changes to these values between 1993 and 2009. For ease of reading, the symbols are not plotted for 2009.

Table 2: Distance between home and activity place by survey zone in Bogotá in 1993 and 2009

Survey zone	Children			Students			Adults		
	Average distance (km) between home and primary or secondary school			Average distance (km) between home and place of further study			Average distance (km) between home and place of work		
	1993	2009	Change 1993-2009	1993	2009	Change 1993-2009	1993	2009	Change 1993-2009
Bosa	1.6	1.8	+ 0.3	0.0	1.3	+ 1.3	6.5	7.4	+ 0.9
Chia	1.3	2.5	+ 1.2	4.9	3.5	- 1.4	9.5	7.2	- 2.4
Gustavo Restrepo	1.3	1.1	- 0.2	1.3	1.9	+ 0.6	3.9	4.6	+ 0.7
La Candelaria	1.5	1.4	- 0.1	0.3	0.1	- 0.2	5.3	3.5	- 1.8
Madrid	1.5	1.6	+ 0.2	1.0	1.3	+ 0.3	4.2	2.8	- 1.4
Normandia	3.3	1.1	- 2.1	3.5	5.7	+ 2.2	4.4	4.6	+ 0.3
Perseverancia	1.9	1.9	+ 0.1	0.3	0.2	- 0.1	2.6	3.6	+ 0.9
San Cristobal Norte	2.6	1.7	- 0.9	1.0	2.6	+ 1.6	7.1	4.9	- 2.2
Soacha	2.9	2.6	- 0.3	0.4	2.8	+ 2.4	7.7	7.6	- 0.1
<i>Overall total</i>	2.0	1.7	- 0.3	1.3	2.1	+ 0.8	5.6	5.3	- 0.3

NB: distances by survey zone result from averages obtained using distances calculated for each of the individuals between the centroid of the home block and the centroid of the destination sector (Euclidean distance).

Sources: CEDE-ORSTOM 1993 and ANR METAL 2009 surveys, Bogotá. Data processing: F. Demoraes. Reference population: individuals co-residing in households with at least one adult in work and at least one child in education.

- 38 Any analysis of changes in individuals' access to place of activity over a sixteen-year period in a Latin American city needs to be placed in the context of the rapid changes which took place over the same period, particularly changes to the demographic structure, and to household composition which was far more diversified in 2009 than in 1993. As observed in Gouëset *et al.* (2014: 287-288), societal changes such as an ageing population, and increased length of studies (leading to later entry into the labor market, in turn leading children to leave the parental home at a later stage and enter the matrimonial and reproductive cycle correspondingly later), influence the configuration of daily mobilities. Equally, shifts in areas of employment and education, transformations to the transport system, and urban sprawl were all factors reconfiguring daily mobility practices in the nine survey zones in Bogotá between 1993 et 2009.
- 39 Several observations may be made. First (figure 2), there are virtually no instances of convergent changes for the three categories of individuals (co-residing adults, schoolchildren, and students), with the exception of the San Cristobal Norte zone, where accessibility improved for each group, and the Gustavo Restrepo zone, where accessibility was broadly unchanged between 1993 and 2009 apart from a slight deterioration for students. Everywhere else, we may observe diverging changes.
- 40 A second observation is the clear deterioration in the accessibility of place of study for students, due to university sites being heavily concentrated in the center of Bogotá, even though there was a slight increase in higher education provision on the peripheries between 1993 and 2009, and even though the comparison may only be

established for five zones given the very low number of individuals concerned at both dates (table 1).

Table 3: Modes of travel by survey zone and by category of individuals (working adults, schoolchildren, students) in Bogotá in 1993 and 2009

Mode (%)	Survey zone																																			
	Perseverancia			La Candelaria			Normandia			Gustavo Restrepo			San Cristobal			Bosa			Chia			Madrid			Soacha											
	Adults	Schoolchildren	Students	Adults	Schoolchildren	Students	Adults	Schoolchildren	Students	Adults	Schoolchildren	Students	Adults	Schoolchildren	Students	Adults	Schoolchildren	Students	Adults	Schoolchildren	Students	Adults	Schoolchildren	Students	Adults	Schoolchildren	Students	Adults	Schoolchildren	Students						
1993																																				
Walking	16.4	63.0	16.7	38.8	16.7	83.7	11.1	50.8	1.0	36.1	4.8	12.2	7.0	81.1	0.0	30.1	12.1	59.5	0.0	36.1	7.6	80.2	-	45.5	10.2	72.7	0.0	34.2	23.0	81.3	25.0	52.9	6.2	73.3	-	38.0
Private car	6.8	5.5	0.0	5.9	3.6	0.0	0.0	1.6	19.6	11.5	7.1	14.6	10.0	6.7	6.3	8.3	14.0	7.9	9.1	10.7	2.5	0.0	-	1.2	8.5	4.5	0.0	6.3	6.9	3.1	0.0	4.8	1.2	1.3	-	1.3
At home	31.5	0.0	0.0	15.1	15.5	0.0	0.0	6.8	35.3	0.0	0.0	17.6	43.0	0.0	0.0	20.9	23.4	0.0	0.0	10.2	22.8	0.0	-	10.9	28.8	0.0	0.0	15.3	13.8	0.0	0.0	6.4	29.6	0.0	-	15.2
Motorbike or bike	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.5	0.0	0.0	0.0	0.0	4.0	2.2	0.0	2.9	0.9	0.8	0.0	0.8	0.0	2.3	-	1.2	11.9	4.5	0.0	8.1	20.7	3.1	0.0	11.2	0.0	0.0	-	0.0
Other system	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	-	0.6	0.0	0.0	12.5	0.9	0.0	0.0	0.0	0.0	0.0	0.0	-	0.0
Public transport	45.2	31.5	83.3	40.1	63.1	16.3	88.8	40.3	44.1	52.5	88.1	55.6	36.0	30.0	93.8	37.9	49.5	31.7	80.3	42.2	67.1	16.3	-	40.6	40.7	18.2	87.5	35.1	35.6	12.5	75.0	24.6	83.0	25.3	-	45.6
Number of individuals	73	73	6	152	84	98	9	191	102	61	42	205	100	90	16	206	107	126	11	244	79	86	0	165	59	44	8	111	87	96	4	187	81	75	2	158
2009																																				
Walking	25.7	57.7	-	40.6	33.8	81.2	-	55.7	1.7	45.0	0.0	9.7	17.0	72.3	5.3	36.0	14.8	88.8	0.0	36.1	7.8	81.3	14.3	41.5	10.0	33.3	33.3	20.2	19.2	79.1	40.0	52.1	12.1	82.9	0.0	38.7
Private car	0.0	0.0	-	0.0	1.3	1.4	-	1.3	22.4	25.0	12.0	20.4	2.1	3.1	0.0	2.2	3.3	3.9	0.0	3.3	0.0	1.1	0.0	0.5	16.0	9.1	0.0	12.4	1.4	0.0	0.0	0.6	1.0	0.0	0.0	0.6
At home	20.0	0.0	-	10.9	26.0	0.0	-	13.4	22.4	0.0	0.0	12.6	22.3	0.0	0.0	11.8	18.0	0.0	0.0	9.0	26.5	0.0	0.0	13.5	44.0	0.0	0.0	24.7	24.7	0.0	0.0	10.7	20.2	0.0	0.0	11.0
Motorbike or bike	2.9	0.0	-	1.6	9.1	1.4	-	5.4	0.0	0.0	0.0	0.0	2.1	1.5	5.3	2.2	1.6	3.9	0.0	2.5	12.7	5.5	0.0	9.0	6.0	12.1	0.0	7.9	21.9	11.0	0.0	15.4	4.0	0.0	0.0	2.2
Other system	0.0	0.0	-	0.0	1.3	2.9	-	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	1.6	1.0	1.1	0.0	1.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.6	2.0	0.0	0.0	1.1
Public transport	51.4	42.3	-	46.9	28.6	13.0	-	22.1	53.4	30.0	88.0	57.3	56.4	23.1	89.5	47.8	59.0	23.5	100.0	47.5	52.0	11.0	85.7	34.5	24.0	45.5	66.7	34.8	31.5	9.9	60.0	20.7	60.6	17.1	100.0	46.4
Number of individuals	35	26	3	64	77	69	3	149	58	20	25	103	94	65	19	178	61	51	10	122	102	91	7	200	50	33	6	89	73	91	5	169	99	70	12	181

For instance: a proportion of 16% of adults residing in Perseverancia stated that they walked to work in 1993, as against 26% in 2009. The "-" sign indicates less than 4 observations.

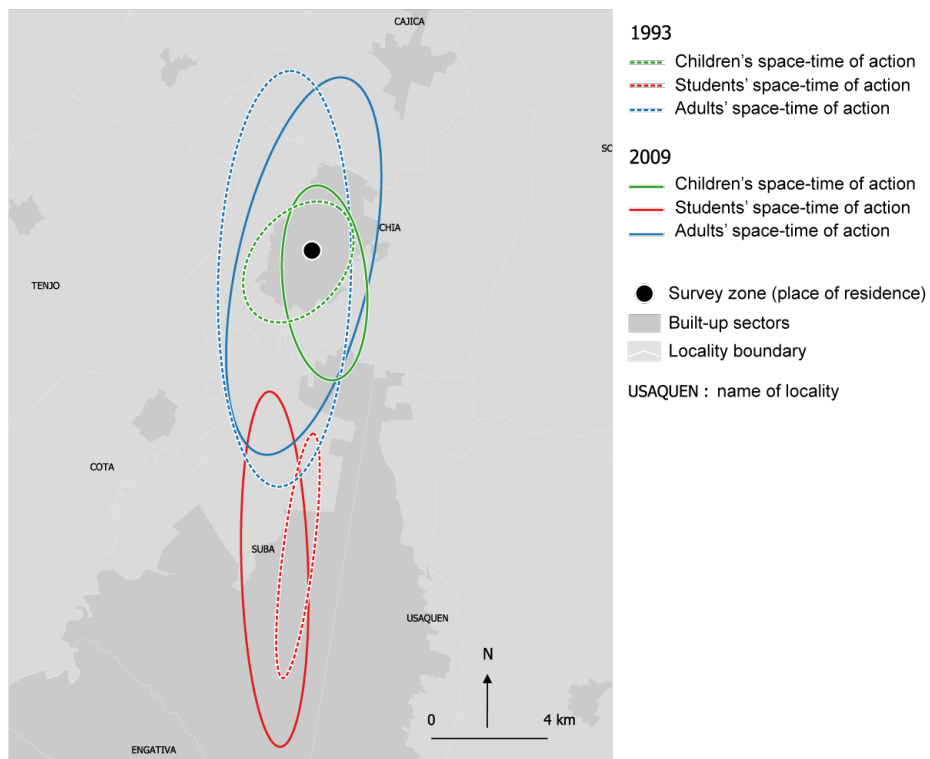
Sources: CEDE-ORSTOM 1993 and ANR METAL 2009 surveys, Bogotá. Data processing: F. Demoraes, M. Bouquet. Reference population: individuals co-residing in households with at least one adult in work and at least one child in education.

- 41 In what follows (maps 8 to 10), we have decided to present only a selection of three zones—starting from the periphery and working towards the center of the metropolitan area—which are illustrative of the observed differences in the respective evolution of the accessibility of place of study or work for children, students, and adults.

5.1. Chía: highly contrasting travel conditions for children, students, and parents

- 42 The first zone selected for discussion is Chía (map 7), a survey zone located in a suburban municipality outside the District Capital (map 1). Urban sprawl has resulted in new economic activity and new, mainly middle-class and wealthy residents arriving in what used to be a rural municipality. Very pronounced contrasts may be observed between the three population groups' daily mobility, as indicated from the outset by the very different sizes, shapes, and positions of their STAs.

Map 7: Changes in the accessibility of place of activity for children, students, and working adults for the Chía zone between 1993 and 2009



Reference population: individuals co-residing in households with at least one adult in paid work and at least one child in education

Author: F. Demoraes. Sources: CEDE-ORSTOM 1993 and ANR METAL 2009 surveys, Bogotá. Data processing: F. Demoraes, M. Bouquet

- 43 Thus Chía is the zone with simultaneously the greatest drop in distance from home to work for adults between 1993 and 2009 (-2.4km, table 2), and, over the same period, the greatest increase in distance for children from home to school (+1.2km). The distance travelled from home to work in Chía was the highest of all nine zones, standing at 9.5km in 1993 and 7.2km in 2009. This may be explained by the number of those travelling towards Bogotá (as may be deduced from the orientation of the blue ellipses), where many inhabitants from this municipality work. The recorded drop in the length of commutes to and from work between 1993 and 2009 may be partly explained by the increase in the number of those working at home (44% of the total of those in work in 2009, as against 29% in 1993, table 3), in turn linked to the shift of economic activity outwards towards the suburban municipalities around Bogotá. For those not working at home, there was a slight drop in the use of public transport (only 24% of journeys in 2009, as against 41% in 1993) and increase in car usage (rising from 8% to 16% of journeys between two dates, table 2). These changes signal Chía's increased integration in the Bogotá employment area, with, on the one hand, jobs moving towards the periphery, and, on the other, commuters going to the District Capital each day by car or by bus.
- 44 Students from Chía experienced an opposite change.¹⁶ This was the zone where the accessibility of students' place of study deteriorated the most. This may be seen both in the size of the red ellipses (that for 2009 being clearly larger than that for 1993) and by the length and orientation of the arrows on figure 2 (towards the top and right of the

diagram). This deterioration is attributable to the fact that the universities continued to be largely concentrated in the center of Bogotá, as indicated by the position of the red ellipses, which lie a long way south of the survey zone. It may also be explained by the fact that students depend on public transport to go to their place of study (table 3), the speed of which did not improve between the two dates. Admittedly there was an increase in the number of courses available locally over the same period (two students surveyed in 2009 studied in Chía and walked to their place of learning), but not enough to reverse the general trend.

- 45 The situation for schoolchildren is more contrasting, with the average distance to school rising notably between the two dates (+1.2km, table 2). This increase may be attributed to three factors: 1. The arrival of several private secondary schools, reputed to be average or good, outside the built-up area of Chía, which explains the change in shape and orientation of the green ellipses between 1993 and 2009 2. The fact that a small proportion of children still go to school in prestigious establishments in the center of the capital 3. The reduction in the relative weight of local public schools. This increase in average distance to school explains in turn the very visible drop in the number walking to school between the two dates (from 73% to 33%, table 3), with a shift towards public transport (rising from 18% to 46%), even though this was in very many cases the school bus service reserved exclusively for schoolchildren. This mode of transport is more rapid than the bus service available to the general public, which explains why the size of the ellipses only increased very slightly between 1993 and 2009.

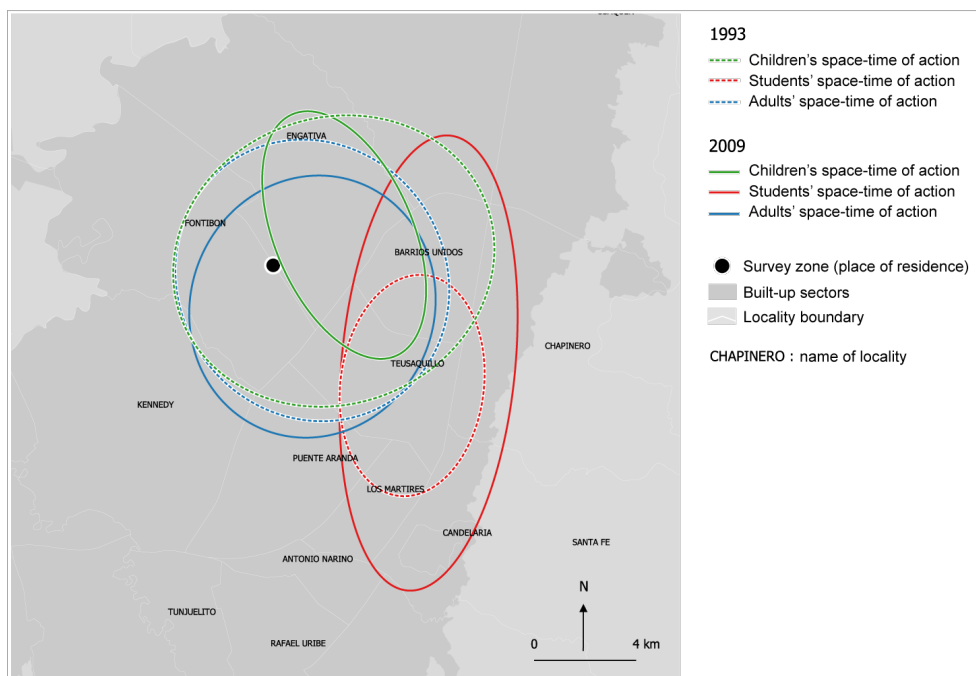
5.2. Normandía: students burdened by living in a far more favorable location for parents and children

- 46 The second zone worthy of attention is Normandía (map 8), an inner suburb neighborhood inside the District Capital (map 1). This zone underwent rapid residential expansion in the 1970s, becoming progressively denser over the course of the 1980s and 1990s (Le Roux, 2015: 155) when small collective housing developments were built. Between 1993 and 2009 the generally middle-class population aged, and household income increased (Le Roux, 2015: 184). This ageing was partially compensated by the building of new housing, which now attracts younger households (*ibid.*: 196).
- 47 As may be seen on map 8, this zone is especially characterized by the contrast between the accessibility of schoolchildren's place of study, which improved markedly (with a far smaller green ellipse in 2009), with that of students, which deteriorated markedly (with a far bigger red ellipse in 2009). The average distance between home and place of study was divided by a factor of three for schoolchildren between 1993 2009 (table 2) thanks to an increased number of local primary and secondary schools, enabling children to depend less on public transport and either walk to school or be driven there by their parents (accounting respectively for 45% and 25% of journeys in 2009, as against 36% and 11.5% in 1993). For students, the opposite happened. It was the study zone with the longest commutes (5.7km), with a sharp rise between the two dates (+2.2km, table 2). Normandía lies at a considerable distance from the universities in the center and from the new establishments which opened to the north of the capital outside the District. This may be observed on map 8 with the red ellipses lying far to the east of the survey zone. Furthermore, as shown on figure 2, the length and

orientation of the arrow towards the top right of the diagram indicates the greater dispersal of places of further education attended and the greater time taken to travel there. This increase in travel time is due to the massive use of public transport (used by nine out of ten students at both dates, table 3), which is dependent on traffic conditions in the city center, which deteriorated between 1993 and 2009.¹⁷

- 48 The situation for adults underwent lesser change than that for children and students between 1993 and 2009, with the position of the blue ellipses on map 8 being fairly similar for the two dates, though improving slightly (the blue ellipse for 2009 being a bit smaller than that for 1993). The distance between home and work remained stable, at around 4.5km (table 2), and the proportion working at home dropped from 35% to 22%, though this was compensated by the lesser dispersal of jobs in 2009 than in 1993 (figure 2) thanks to the emergence of new business zones near Normandía, in Ciudad Salitre, along the El Dorado avenue, and around the airport (map 3) among other areas.

Map 8: Changes in the accessibility of place of activity for children, students, and working adults for the Normandía zone between 1993 and 2009



Reference population: individuals co-residing in households with at least one adult in paid work and at least one child in education

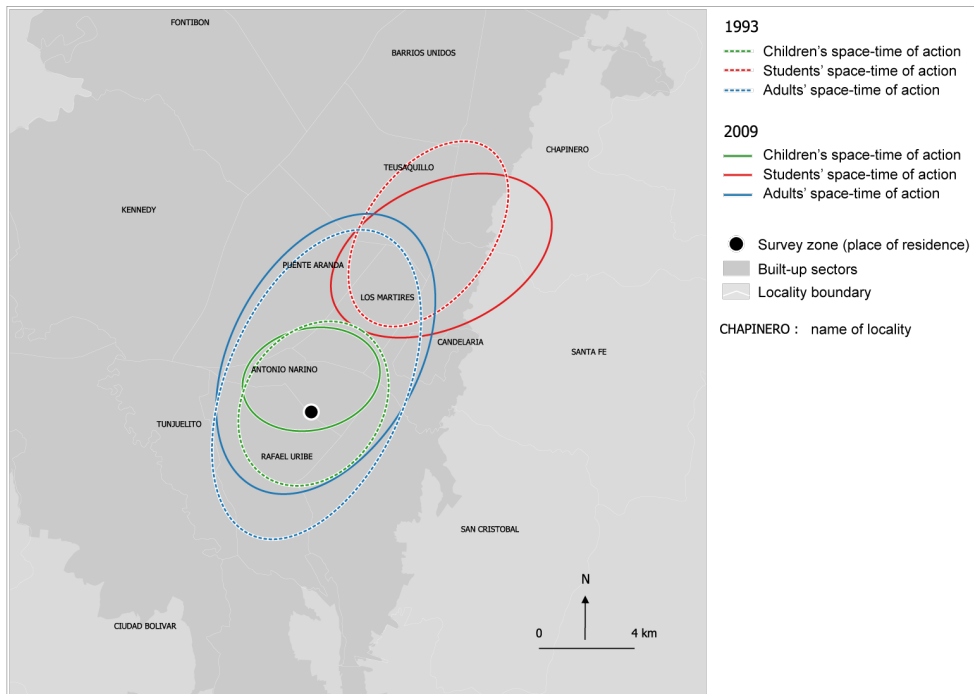
Author: F. Demoraes. Sources: CEDE-ORSTOM 1993 and ANR METAL 2009 surveys, Bogotá. Data processing: F. Demoraes, M. Bouquet

5.3. Gustavo Restrepo: proximity to the center benefiting all categories

- 49 The third and final zone examined here is Gustavo Restrepo (map 9), lying in the inner suburbs of Bogotá (map 1). This neighborhood near the city center has long been a built-up area,¹⁸ with a majority of what were originally unauthorized, working-class dwellings. There are also many businesses and industrial activities in this zone (map 3).

Gustavo Restrepo is illustrative of the advantageous situation of neighborhoods in the center and inner suburbs of the city.¹⁹

Map 9: Changes in the accessibility of place of activity for children, students, and working adults for the Gustavo Restrepo zone between 1993 and 2009



Reference population: individuals co-residing in households with at least one adult in paid work and at least one child in education

Author: F. Demoraes. Sources: CEDE-ORSTOM 1993 and ANR METAL 2009 surveys, Bogotá. Data processing: F. Demoraes, M. Bouquet

- 50 In both 1993 and 2009, children traveled short distances (1.3km, then 1.1km, table 2), in the majority of cases by foot (61%, then 72% of journeys, table 3), illustrating the long-standing density of available schooling in this neighborhood, and the working-class profile of the families living in Gustavo Restrepo, who, being unable to pay the fees for the smart schools to the north of the city, make do with those in the locality. This neighborhood effect transpires in the position of the green ellipses, which are pretty much centered on the survey zone, and in their size, being particularly small, especially in 2009, indicating an improvement in accessibility since 1993.
- 51 For the two other categories (students and parents), the central location of the neighborhood guarantees relatively easy access to the resources in the center (jobs and universities), even when using public transport at rush hour. It is thus one of the zones with the greatest stability between the two dates in accessibility of place of activity for all three categories of individuals (figure 2). It is particularly one of the few zones in the city where students' mobility conditions did not deteriorate between 1993 and 2009. Admittedly, the average distance to place of study rose slightly by 2009 (+0.6km), but it remained low (1.9km, table 2). Furthermore, while students depended on public transport (for 90% of them), they travelled short distances, resulting in a limited increase in travel time (on map 9, the red ellipse for 2009, though slightly larger than that for 1993, largely overlays it). Despite students in Gustavo Restrepo being working

class, their mobility conditions were thus better than those for students in suburban areas.

- 52 The situation of parents was virtually unchanged between the two dates (with nearly identical blue ellipses, map 9). The distance between home and work was slightly longer in 2009 (+0.7km, table 2), due especially to the halving of the number of those working at home (table 3). The large number of jobs locally available (map 3) explains the increase in those walking to work, which accounted for 17% of commutes in 2009, a figure only exceeded by zones in the city center (Perseverancia, La Candelaria, and Madrid).

6. Conclusion: the interests and limitations of the concept of space-time of action, and prospects for future use

- 53 The purpose of this article was to introduce a new concept that we have called space-time of action, corresponding to the entire set of individuals' destinations for work or study and the time taken to go there on a daily basis. We have made this concept operational by calculating and mapping ellipses for our case study of Bogotá. To this end, we have taken inspiration from two tried and tested sets of methods, the first from the field of cartography, the second from that of spatial analysis. As far as we know, these two sets of methods have never previously been combined to measure the accessibility of individuals' place of activity. Calculating STAs is simple using a GIS, only requiring three input variables (origin, destination, and travel time). It may thus be applied to numerous surveys for which individual-level data is available. Furthermore, even though it is not an exclusive feature of this metric, travel times are not averaged by destination sector, which would have the effect of erasing disparities between individuals. It is only at the stage of calculating ellipses that individual positions are synthesized by group, which presents the advantage (which though not an initial objective nevertheless meets an ethical requirement) of maintaining confidentiality once these positions are mapped. Mapping the STAs using ellipses also provides a way of showing several groups on a single map, and in the case studied here at two different dates, and thus avoids multiplying the number of maps. However, an ellipse remains a schematic representation of the places actually frequented, supplemented, moreover, by a temporal aspect, and so interpreting them can take some adaptation.
- 54 Additionally, while STA maps are of real benefit for describing changes in accessibility to individuals' place of activity between two dates, as we have seen, more conventional variables (such as distance between home and place of activity, spatial dispersal of destinations, and mode of transport) are required to supplement interpretation. Furthermore, STAs for the two dates provide a measure of accessibility to place of activity aggregated by group. In this article STAs thus show changes in how three co-residing categories of individuals (working adults, students, schoolchildren) relate to metropolitan space. They thus bring out groups whose situation improves or deteriorates over time in comparison to other groups. Still, STAs do not enable us to directly apprehend arrangements and trade-offs within families, which can only be brought out by qualitative analysis (based on in-depth interviews, for example, conducted at both dates).

- 55 Above and beyond the use made of space-time of action in this article, the concept could be applied to many other domains, in a diachronic perspective or else simply for a given date. It could be useful for studying discrepancies in accessibility to place of work for many other groups of individuals (men/women, handicapped people, etc). STAs could thus be used for longitudinal study of changes in the accessibility to healthcare facilities of patients with a chronic illness, with a view to reorganizing healthcare provision within a territory. The concept also seems suitable for monitoring transformations in center-periphery relations (a retraction in STAs between two dates indicating improved connectivity) or else studying how introducing a BRT service can boost contact possibilities within an agglomeration.
- 56 In addition to this methodological contribution, this article draws on two particularly precious surveys making it possible to follow changes in accessibility of place of work or study for three categories of individuals at a sixteen-year interval. These data sources are without equivalent for Bogotá for the period under study. This article has thus provided an opportunity to illustrate the potential for reusing relatively old survey data, and the precautions that need to be taken. This echoes two problems identified by Heaton (2008): the problem of "data fit" (the fit of a dataset devised by one group of researchers for new questions addressed by other researchers), and the problem of "not having been there" (the authors of this article took part in the 2009 survey, but not in that of 1993). Over recent years, there has been much debate in the scientific community about reusing surveys produced using public funding, particularly in the human and social sciences given the specificity of data in this domain (Serres *et al.*, 2017). At the same time, online platforms have been developed in France such as the beQuali initiative, a bank of qualitative surveys in the human and social sciences,²⁰ and the Quetelet PROGEDO Diffusion web portal, providing access to data from major surveys conducted by French researchers.²¹ For our part, the analysis presented in this article was made possible thanks to several factors. First, we had access to very rich documentation describing the purposes guiding how these surveys were devised, their implementation protocols, and all of the variables for both dates. Second, the existence of a PhD thesis (Le Roux, 2015) was of particular use for checking the comparability of the two surveys concerning daily mobility. Third, we benefited from the readiness of the scientific leader of the two surveys (F. Dureau) to spend time answering our questions.

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Software used

Stata, Excel, SavGIS, QGIS

APPENDIXES

Table 4: Coordinates of place of residence and of activity (excerpt), ANR METAL, Bogotá, 2009

Individual ID	Survey zone	Residence X Geo (°)	Residence Y Geo (°)	Residence X Proj (m)	Residence Y Proj (m)	Activity X Geo (°)	Activity Y Geo (°)	Activity X Proj (m)	Activity Y Proj (m)
01100301	Perseverancia	-74.068649	4.61901999	101366	102207	-74.15739	4.69633007	91515	110759
01100303	Perseverancia	-74.068649	4.61901999	101366	102207	-74.12311	4.67437983	95320	108331
01100304	Perseverancia	-74.068649	4.61901999	101366	102207	-74.08019	4.59890985	100084	99982
01100701	Perseverancia	-74.065437	4.61978006	101722	102291	-74.11017	4.63593006	96756	104077
01100703	Perseverancia	-74.065437	4.61978006	101722	102291	-74.07337	4.61048985	100841	101263
01101203	Perseverancia	-74.06649	4.61920977	101605	102228	-74.06764	4.62047005	101477	102367
01101602	Perseverancia	-74.070396	4.61527014	101172	101792	-74.07096	4.6198802	101109	102302
01101901	Perseverancia	-74.069649	4.62099981	101255	102426	-74.07951	4.70937014	100159	112202
01101902	Perseverancia	-74.069649	4.62099981	101255	102426	-74.06388	4.6381402	101895	104322
01105101	Perseverancia	-74.06649	4.61920977	101605	102228	-74.05209	4.66767979	103203	107590
01105102	Perseverancia	-74.06649	4.61920977	101605	102228	-74.14414	4.58501005	92985	98444

Table 5: Intermediary variables calculated to obtain the coordinates for place-times of activity (excerpt) - ANR METAL – Bogotá – 2009

Individual ID	Travel time (min)	OD Euclidian distance (m)	Speed (m/min)	Speed (km/h)	Overall average speed (m/min)	Distance Time (m)	Orientation (°)	Cosine (radians)	Sine (radians)	Delta X (m)	Delta Y (m)	PTA X Proj (m)	PTA Y Proj (m)
01100301	60	13045	217.4	13.0	180	10800	138.9	-0.753986478	0.656889915	-8143	7094	93223	109301
01100303	30	8605	286.8	17.2	180	5400	134.5	-0.701280355	0.712885618	-3787	3850	97579	106056
01100304	15	2567	171.1	10.3	180	2700	240.1	-0.497821212	-0.867279649	-1344	-2342	100021	99865
01100701	30	5277	175.9	10.6	180	5400	160.1	-0.940573454	0.339590281	-5079	1834	96643	104125
01100703	10	1353	135.3	8.1	180	1800	229.5	-0.649446845	-0.760407031	-1169	-1369	100553	100922
01101203	10	189	18.9	1.1	180	1800	132.4	-0.674699664	0.738092363	-1214	1329	100391	103556
01101602	5	513	102.6	6.2	180	900	97.0	-0.12155769	0.992584348	-109	893	101062	102685
01101901	40	9837	245.9	14.8	180	7200	96.4	-0.110941082	0.993826985	-799	7156	100456	109581
01101902	10	2001	200.1	12.0	180	1800	71.4	0.318931639	0.947777748	574	1706	101829	104132
01105101	30	5595	186.5	11.2	180	5400	73.5	0.284727931	0.958608389	1538	5176	103143	107404
01105102	30	9413	313.8	18.8	180	5400	203.8	-0.915172338	-0.40306282	-4942	-2177	96663	100051
01105104	30	3295	109.8	6.6	180	5400	97.4	-0.129584044	0.991568446	-700	5354	100905	107582
01105105	10	3435	343.5	20.6	180	1800	194.3	-0.969222128	-0.246187881	-1745	-443	99861	101785
01105106	40	802	20.1	1.2	180	7200	201.9	-0.928125858	-0.372266531	-6683	-2680	94923	99547
01105201	1	533	533.0	32.0	180	180	154.0	-0.898477435	0.43901971	-162	79	101211	102369
01105202	30	1879	62.6	3.8	180	5400	225.0	-0.706909955	-0.707303524	-3817	-3819	97555	98470
01105203	10	263	26.3	1.6	180	1800	177.3	-0.998924196	0.046372965	-1798	83	99574	102373
01105604	5	130	26.0	1.6	180	900	36.5	0.803872883	0.594801128	723	535	102096	102825
01105804	25	4115	164.6	9.9	180	4500	104.2	-0.246147737	0.969232321	-1108	4362	100064	106153
01105805	25	4115	164.6	9.9	180	4500	104.2	-0.246147737	0.969232321	-1108	4362	100064	106153
01106301	15	734	48.9	2.9	180	2700	201.0	-0.933697939	-0.358061612	-2521	-967	98602	100929
01106302	60	22159	369.3	22.2	180	10800	83.6	0.111339144	0.993782461	1202	10733	102325	112629
01106303	60	22159	369.3	22.2	180	10800	83.6	0.111339144	0.993782461	1202	10733	102325	112629
01109401	10	1862	186.2	11.2	180	1800	236.1	-0.557562888	-0.83013469	-1004	-1494	100602	100841

NOTES

1. Program funded by the Agence Nationale de la Recherche, under the title "Le rôle des cultures éducatives urbaines (CEU) dans l'évolution des mobilités quotidiennes et des contextes de vie des enfants. Collecte et analyse de traces géolocalisées et enrichies sémantiquement" (The role of urban educational cultures in changes to children's daily mobility and the circumstances in which they live. Collection and analysis of semantically enriched geo-localized tracking) - <https://anr.fr/Projet-ANR-16-CE22-0009>
2. A joint program conducted by the CEDE (*Centro de Estudios sobre Desarrollo Económico de la Universidad de los Andes*) and ORSTOM, the former name of the IRD (*Institut de Recherche pour le Développement*).
3. Research program funded by the Agence Nationale de la Recherche, under the title: "Métropoles d'Amérique latine dans la mondialisation. Reconfigurations territoriales, mobilité spatiale, action publique".
4. For an in-depth study of all the methods which may be used to map action spaces (ellipses, travel probability fields, kernel density estimates, minimum convex-hull polygons, network-based buffer zones, etc.), consult Patterson and Farber (2015), Kwan et al. (2019) and Vich et al. (2017).
5. Individuals from disadvantaged households residing in central spaces may have relatively shorter travel times. This is, however, only infrequently the case.
6. <http://migrinter.labo.univ-poitiers.fr/metalmaps/webmaps.html>
7. A dynamic cartogram showing the evolution of socio-residential segregation in Bogotá from 1993 to 2005 is available at: <http://espenf.cnrs.fr/AnamorphoDyn/>

8. According to the origin-destination surveys conducted in the Bogotá Metropolitan area at these two dates.
 9. BRT: Bus Rapid Transit.
 10. Groupe de Réflexion sur l'Approche Biographique (Ined).
 11. A presentation (in French) of the methodology may be found in Dureau *et al.* (2014: Chap.2).
 12. At both dates it took one and a half hours on average to survey one household.
 13. STAs were calculated using SavGIS, a free GIS software developed by Marc Souris (IRD): <http://www.savgis.org/SavGIS/accueil.html>. But the method may be reproduced using any other GIS.
 14. Mode of transport is brought into consideration for the interpretation of results (section 5).
 15. These coordinates correspond to the variables "X_Proj_home" and "Y_Proj_home".
 16. The number of students in our reference population in Chía was nevertheless low (8 in 1993 and 6 in 2009), hence the observed results should be taken with caution.
 17. It should be pointed out that the *Transmilenio* line linking the airport to the town center—and hence Normandía to the universities—had not yet entered service in 2009. It opened in 2014, since when the situation has improved for students.
 18. 77% of the dwellings surveyed in 2009 had been built prior to 1980 (Dureau *et al.*, 2014: 65).
 19. It was not possible to analyze the situation for the two survey zones in the town center, Perseverancia and La Candelaria, due to the low number of students in our 2009 reference population.
 20. <https://bequali.fr/fr/pour-quoi-faire/>
 21. <http://quetelet.progedo.fr/>
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ABSTRACTS

The purpose of this study is to understand changes to household members' access to place of activity, against the backdrop of urban and socio-demographic transformation. In particular, it seeks to establish whether adults are currently disadvantaged by residing in a location which, in terms of daily mobility, is better suited to their children, or whether other factors are at work, depending particularly on the household's position in the social hierarchy. It further seeks to understand how mobility conditions have changed over time depending where individuals reside in the city. To this end, it puts forward a new concept called "space-time of action" and proposes a way of mapping it. Drawing on data from two surveys in Bogotá (Colombia) in 1993 and in 2009, "space-times of action" are here used to study joint changes to co-residing working adults' and children's access to place of work or study. It details how the space-times of action were devised, before then discussing their advantages and limitations.

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