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To cite this version:

Cyrille Genre-Grandpierre, Cyril Sahuc, Serigne Gueye. Speed vs locations: Accessibility level evaluations. The case of the Ring of Sciences in Lyon. Case Studies on Transport Policy, 2018, 6 (3), pp.423-431. 10.1016/j.cstp.2018.04.001 . hal-02280400

Speed *vs* locations: accessibility level evaluations

The case of the Ring of Sciences in Lyon

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Abstract

For a long time, the cost-benefits evaluation of new road infrastructure, built in order to improve accessibility, has mainly been based on the time saving involved. This time is “monetized” and enables a decision as to whether the infrastructure is cost effective or not for a given time span. This method often promotes the building of high speed infrastructures to reduce travel time with, in the medium term, automobile dependency as a consequence. In today’s context of lower funding and the search for greater sustainability, the goal of this work was to evaluate if it is possible to reach good levels of accessibility by efficiently relocating facilities (in this study jobs) rather than by building new road infrastructure. We want to illustrate to what extent it is possible to make accessibility less dependent on travel speed, by changing job locations to reduce travel time. We have developed a simulation platform coupling a geographical information system and an algorithm for optimal relocations, and illustrate its use through the case of the Ring of Science road project in Lyon (France).

K*eywords:* Accessibility planning; Relocation; Optimization; Speed; Infrastructure evaluation

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1. Introduction

Accessibility, which can be defined as the quantity of resources (people, jobs, services) accessible from a given location, in a given time, by a given mode of transport (Handy, Niemeier 1997), lies at the heart of urban development (Batty, 2013). At an individual level, accessibility to people (the "Social Interaction Potential", Farber et al. 2014) enables the promotion of social life through the exchange of information and face-to-face activities (Maslow, 1943; Urry, 2002). In economic terms, a high level of accessibility to jobs encourages coherent matching between job supply and demand, beneficial for both firms and workers (travel time to the workplace is for example directly related to unemployment, Mignot, Rosales-Montano, 2006). More generally, a wide job market and high levels of accessibility to people and to services lead to the emergence of agglomeration economies (Marshall, 1890) by ensuring the transmission of new ideas, thus fostering creativity and innovation. The latter is a key component in economic growth and competitiveness (Prud'homme, Lee, 1999; Glaeser, 2011).

Before the Second World War, when the modes of transport were slow, grouped activities and high population densities were the only way to attain high accessibility as they reduced the travel time. More recently the higher speeds, permitted by car ownership and huge road investments, have given people and firms more freedom to choose their location within larger areas, but without increasing their travel time and then reducing their level of accessibility. The daily travel time budget remains constant at around 1.5 h, even if amenities have become more widely separated (Zahavy, Talvitie, 1980; Levinson, Kumar, 1994). This has led to urban sprawl and to an urban functioning for which accessibility is based on car speed (as a means to minimize travel time) rather than on physical proximity.

In urban functioning this crucial importance of speed to provide high accessibility explains why the cost-benefits evaluation of new road infrastructure has mainly been based on time saving ("time saved represent 80 to 90% of the measured advantages by the socio-economic evaluation of relevant projects", Boiteux, 2001). This means the time saved is "monetized" and used to evaluate whether the infrastructure is "cost effective" for a given time span. As a result, this method leads to promoting high speed travel as the main lever to reduce travel time and thus to improve accessibility.

The problem is that this approach to urban functioning, mainly based on road infrastructure and car speed and leading to a scattered spatial structure, appears to be neither suitable nor possible in the medium term because:

- it makes people highly automobile reliant (Newman, Kenworthy, 1989; Dupuy, 1999). Without the speed of cars, people are no longer able to perform their daily tasks, particularly in peripheral areas, as they rarely have an alternative mode of transport providing the same travel time as a car.
- it may raise social issues. It lowers the potential for social activity (Farber, Liu, 2013), leading to issues in terms of inequality, because those without a vehicle do not have access to many activities which were located assuming car accessibility.
- it leads to environmental issues as the distances travelled (in kilometers) increase, resulting in higher energy consumption, noise and pollutant emissions.
- and finally, the construction of new high-speed infrastructure seems to be more difficult with today's lower public funding and in a context where the issue of sustainability is becoming more important. This issue of sustainability often goes hand in hand with the pursuit of slowness for safety and for environmental aspects (to decrease pollutant emissions). Slowness is also motivated by the promotion of territorial functioning based more on proximity than on speed (Wiel, 2002; Genre-Grandpierre, 2007), for example with the concept of a short distance-city.

Thus, as this car use-based functioning now appears to be unsustainable, the consideration of possible alternatives is a central topic for urban planners, given that neither people nor planners can renounce accessibility. A first solution aims at providing true cost-effective travel alternatives to the car with public transport. Unfortunately, this is very difficult, especially in low density peripheries and for longer trips. For shorter trips, improved cycling and walking facilities appear to be necessary but are not sufficient to ensure large scale urban functioning. Therefore a shift seems to be needed from planning for mobility to planning for accessibility. According to Banister, "within the sustainable mobility paradigm (Banister 2008), planning has an instrumental role in reducing trip lengths so that proximity or closeness becomes a key consideration in the location of new activity or in the reorganization of existing activities" (Banister, 2011).

Given that accessibility depends on travel time which depends on speed, in order to reach the resource as quickly as possible, but also -as we tend to forget - on the location of basic amenities (i.e. having the resources nearby), the question has become “is it possible to change the current nature of accessibility to reach suitable levels of accessibility through optimal (re)locations of amenities rather than through travel speed provided by new roads?”. This question may involve reorienting the current approaches to infrastructure evaluation by searching for the conditions under which it is possible to do without new roads, rather than trying to evaluate such projects from a cost-benefits perspective. In fact, the evaluation process is already no longer limited to the evaluation and monetization of the time saved with a new infrastructure. It is more comprehensive, and analyzes the effects of infrastructure on accessibility and on all the related territorial dynamics. In this process based on accessibility changes, the locations of the points of measurement (i.e. homes) and of the resources (i.e. jobs) are given, and the transportation network is considered as permanent, except for the new infrastructure to be evaluated (Crozet et al., 2013). After computing the accessibility map derived from the new infrastructure, attempts are made to model its effects on land use and more precisely on the location of households and activities, using for instance land-use transport interaction models “LUTI models” (Simmonds et al.,1999), such as *Pirandello* (Piron, Delons, 2008) or *Albatross* (Arentze et al, 2000). Thus, there is a multi-criteria analysis which tries to encompass the transport, environmental, social and economic impacts of the new infrastructure to evaluate its necessity.

However, even for this more comprehensive evaluation processes the general principle remains the same. It consists in analyzing the effects of a new infrastructure on accessibility and the consequences, more than really testing its necessity, which could include investigating the conditions, particularly in terms of relocation of the basic amenities, under which it would be possible to obtain the same results in terms of accessibility but without the new infrastructure. Some can argue that this is due to the lack of tools able to explore the impacts of optimal locations on accessibility. In fact it is quite easy to simulate accessibility changes resulting from new roads. It is also relatively straightforward (with location-allocation methods, Thomas, 2002) to allocate a resource in order to maximize accessibility when the places of demand are known. However, to the best of our knowledge, there is no method or tool which enables the relocation of a resource in order to maximize accessibility for a given set of measurement points when the demand is unknown, or which can indicate the minimum relocation of a resource which provides a given level of accessibility. Thus, in the wide range of research into what accessibility should be from a sustainable perspective, the work described here provides a tool (*Ac-Rel*) to explore the relative importance of speed *vs* (re)locations for accessibility, which in turn may contribute to enriching the evaluation process of the necessity of new transport infrastructure. Briefly, the aim is to know how it could be possible to reduce travel time to increase accessibility by (re)organizing locations to improve proximity, rather than by increasing travel speed. Two approaches are reviewed:

- to relocate a given proportion of a resource to maximize the average accessibility into a study area, in order to see if the level of accessibility forecast for a new infrastructure can be reached or even exceeded
- to find the minimum quantity of resource to optimally add to a given situation in order to reach a pre-determined threshold of accessibility (i.e. that provided by the new infrastructure).

To introduce the *Ac-Rel* tool and its different options, and to illustrate the respective weight of locations and speed in the measurement of accessibility, the case study presented here concerns the Ring of Science (ROS) in Greater Lyon (France). It is an underground motorway planned for 2028 (yet not budgeted for) which aims to link several activity areas located in the west of Lyon and to complete a ring-road around the city in order to improve overall accessibility to jobs (Grand Lyon, 2012). The method consists in classical calculations related to accessibility to jobs with and without the ROS for the employment situation foreseen by Greater Lyon for 2030. This accessibility was then compared to the options obtained with *Ac-Rel* for different optimal relocation scenarios. The calculations were done for the 744 IRIS (small statistical units) of Greater Lyon. All types of jobs were considered, because it is impossible to know all the details for the types of jobs available in 2030. This imposes a limitation from a thematic point of view, because the cost of relocation will vary depending on the types of jobs, but it does not change the methodological approach. The different scenarios for transport and employment location tested with *Ac-Rel* were:

- optimal relocation of jobs planned for 2030 in order to maximize the average accessibility with and without the ROS.
- as above, but simulating an increase of 15 and 30% in the travel time in order to illustrate that it is possible to separate accessibility and travel time.

In this work only accessibility by private vehicles was considered. The Origin-Destination (OD) matrix of the travel time by car between the different IRIS was obtained with the MOSART platform (Bonnafous et al., 2010) which is a geographical information system with a very accurate road network data base for Lyon. Public transport system accessibility could have been included (by changing the OD matrix) to judge overall job accessibility given that public transport is an important alternative to road-based transport. However for this methodological paper, taking public transport into account would have made it difficult to identify the specific contribution of the relocation process on accessibility levels and made fair comparisons more complicated. Moreover the definition of accessibility used (gravity based accessibility) is not, in its current form, compatible with public transport.

The paper begins with a presentation of gravity based accessibility (2.1) which is used to evaluate the gain in accessibility to jobs for Greater Lyon expected with the ROS (2.2). Next, we introduce the optimal relocation method used in *Ac-Rel* (3). Then, the accessibilities provided by the relocation process for different scenarios are compared with the accessibility provided by the ROS (4). Finally, improvements for the relocation method (5) are suggested, with their results, before giving some overall conclusions (6).

2. Gravity-based accessibility to employment in the Great Lyon with and without the Ring of Sciences

2.1. Gravity-based accessibility

Local accessibility reflects the facility to reach from a point *i* a set of *j* place(s) or a resource (jobs) located in *j* with a given transportation system. Accessibility depends both on the spatial organization (the spatial distribution of the resource) and on the quality of the transportation system, which enables the different places where the resource is located to be reached more or less quickly. The convenience of access can be expressed in different ways depending on the issue studied. For example, accessibility may be given by the minimum distance (in km, time etc.) to reach from a starting point *i* the closer resource, or by the distance allowing x% of the resource to be reached, or by the sum of distances to reach all the resource locations. In this work, the gravity based accessibility measurement is used (Geurs and Wee, 2004) which enables for a place *I* to weight a resource in *j* according to its quantity and to the distance between *i* and *j*. The further *j* is from *i*, the less attractive the resource in *j* is for *i*, and the less it will contribute to the accessibility of *i*.

For *i*, the gravity accessibility is given by:

$$A_i = j\ D_j\ exp(-\beta C_{ij})\ (1)$$

with :

- *Ai* accessibility in *i* (the centers of the different Greater Lyon IRIS),
- *Dj* the resource in *j* (the jobs)
- β a parameter which gives the sensitivity to the generalized cost of transport (0.18)
- *Cij* the generalized cost (in €) of transport between *i* and *j* given by:

$$Cij=Cmij+Tij*VdT$$

with :

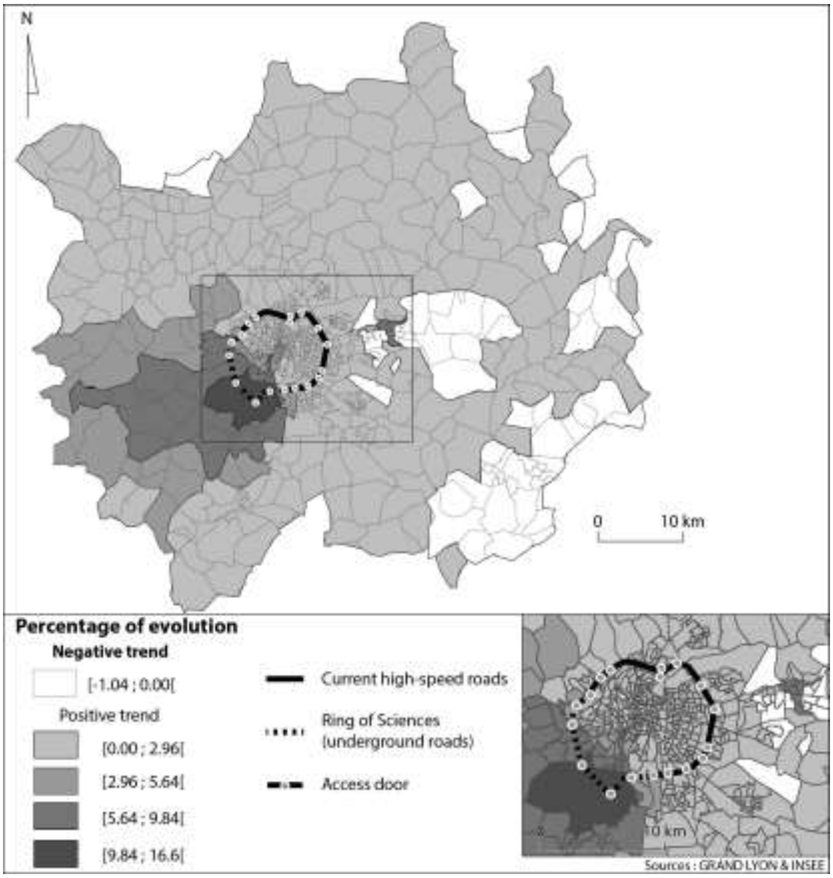
Cmij the monetary cost in euro, set at 0.49 €, which depends on the distance in kilometers from *i* to *j* and on a mean cost per kilometer (which includes the fuel, the maintenance of the vehicle, and insurance)

Tij the travel time in minutes between *i* and *j* during peak hours, and *VdT* the value of time in euro per hour. This value is debatable (for example, it may change depending on the population category) and is set at 11.40 € for this work, as defined by the French government for urban journeys.

2.2. Gravity based accessibility to employment in Greater Lyon with and without the Ring Of Sciences

First, gravity accessibility was used in order to measure how the ROS changes accessibility to employment for the 743 IRIS. They had 1,647,722 inhabitants with 803,479 jobs in 2010, and the forecasts for Greater Lyon give 1,982,833 inhabitants and 982,775 jobs in 2030. Planned for 2028, the ROS is a 14.8 km motorway located in the west of Lyon. It will be part of a ring road around Lyon once connected to the motorway which currently allows the city to be bypassed by the East. By linking several activity areas in the west to the rest of the city, the ROS is intended to improve accessibility to jobs in Greater Lyon and to encourage economic development on the west side.

Whether the figures for jobs in 2010 or for jobs forecast for 2030 are used, the computation of gravity based accessibility shows that the ROS should logically improve job accessibility, but only to a limited extent as the mean gain for the IRIS is only 2% (maximum 16.6%). The input data for job locations and transportation costs were the same between the two simulations with and without ROS. Thus a positive change in accessibility (in dark grey on the map) represents a reduction in travel costs due to the decrease in travel time. Geographically, the main gains are logically in the west, close to the ROS, but they also occur in other areas more or less well connected to the ROS. The slight decrease in accessibility (in the east) is due to minor changes planned for the road network there when the ROS will be added. This level of accessibility provided by the ROS in 2030 will be used as a reference, as the objective is to evaluate to what extent the same level could be achieved only by relocating jobs.



Sources : GRAND LYON & INSEE

Fig. 1. Change in accessibility to jobs in 2030 with and without the Ring Of Sciences

3. Relocation of jobs to maximize accessibility: method

The aim of the method is to relocate jobs in order to maximize the level of accessibility within the study area, or to find the minimum number of new jobs to add and to locate optimally to a given spatial configuration (jobs in 2010), in order to reach a given threshold of accessibility, i.e. that calculated for the ROS to provide in 2030. No attempt is made to reduce the number of job-distance journeys depending on given locations of jobs and workers. The details regarding commutes are unimportant because these may change quickly, so the concern is providing good access to the job market everywhere. In this work, the city is considered as a “potential” of jobs which should be maximized everywhere, because a high accessibility potential is one of the main qualities of urban areas enabling innovation, productivity and resilience (Glaeser, 2011).

In the optimization process D_j the number of jobs per IRIS must be determined. Let I be the set of IRIS with $q = |I|$ the total number of IRIS. The focus is on D_j, where $J \in I$: the number of jobs per IRIS. In order to clearly define the situation, we also assume that there is a total number of jobs T and that each variable has a known upper limit $\overline{D_j}$

$$\mathrm{i.e}\sum_{j\in I} D_j = T, \mathrm{et} D_j \leq \overline{D_j} \forall j \in I$$

Without that upper limit, all jobs would be concentrated on the IRIS with the best position. When $\mathrm{D_j} = \overline{\mathrm{D_j}}$ the IRIS j is "saturated" with jobs. For each IRIS $i \in \mathrm{I}$, accessibility is defined by the quantity:

$$A_i = \sum_{j \in i} D_j \frac{1}{e^{\beta C_{i,j}}}$$

where $C_{i,j} = Cm_{i,j} + T_{i,j}Vdt$ (cf. 2.1)

The average accessibility is then defined by the expression:

$$\frac{1}{q} \sum_{i \in I} A_i$$

Because q is fixed, it is easy to see that finding the position that maximizes the previous expression is equivalent to maximizing only:

$$f(D) = \sum_{i \in I} A_i = \sum_{i \in I} \sum_{j \in I} D_j \frac{1}{e^{\beta C_{i,j}}}$$

By switching the two sums, the equivalent expression is obtained:

$$f(D) = \sum_{j \in I} D_j \left[\sum_{i \in I} . \frac{1}{e^{\beta C_{i,j}}} \right]$$

With

$$\alpha_j = \sum_{i \in I} . \frac{1}{e^{\beta C_{i,j}}}$$

α_j depends only on the values $\mathrm{C_{i,j}}$ (the travel times between IRIS) as the number of jobs or the Origin-Destination flows between IRIS are nowhere in the expression. Because of this, the procedure to compute the optimal positions is relatively simple and can be summarized by the following proposition:

Proposition 1. The values $\mathrm{D_j}$ ($\mathrm{j} \in \mathrm{I}$) maximize the function f(D) (i.e. mean accessibility) if and only if they have the following property:

(P) : For each IRIS j and k, if $\alpha_\mathrm{j} > \alpha_\mathrm{k}$ then either j is saturated (i.e $\mathrm{D_j} = \overline{\mathrm{D_j}}$) or $\mathrm{D_k} = 0$.

Demonstration : The property means that if the value α_j is greater than α_k then the optimal location (i.e. the location that maximizes the mean accessibility) of jobs will saturate the IRIS j or will assign no jobs to k. To demonstrate this property, we can examine a contradiction proof by assuming the opposite. Assuming there are two IRIS j and k in the optimal distribution of the jobs where $\alpha_\mathrm{j} > \alpha_\mathrm{k}$, $\mathrm{D_j} < \overline{\mathrm{D_j}}$ (i.e. j is not saturated) and $\mathrm{D_k} > 0$ (i.e. IRIS k contains jobs). In this case, relocating a job from k to j would be enough to increase the mean accessibility by $(\alpha_\mathrm{j} - \alpha_\mathrm{k}) > 0$, which is absurd because the distribution is considered to be optimal.

The previously discussed property and its corresponding proof lead to a simple procedure to compute the optimal relocation by decreasing order of α_j, can saturate the IRIS with jobs. By this method the property (P) is verified and the computed distribution of positions is necessarily optimal. This method was used with the number of jobs planned for 2030 in Greater Lyon.

The model allows two types of optimization.

- to maximize the mean accessibility of the IRIS. In this case, there are several possibilities:
    - a free relocation of all the jobs. The results of this option will not be presented as they are not realistic. It is highly unlikely that all the jobs are located at the same place, even if it could technically occur.
    - thus, a maximum capacity to host jobs is set for each IRIS. As this capacity does not exist theoretically or in planning and forecast documents such as Local Urban Plans (PLU) or Territorial coherence scheme (SCOT) in France, two possibilities were used. In the first, the number of possible

  jobs for an IRIS corresponded to its population in 2010 * 1.5, while in the second case the number of jobs corresponded to the population in 2030.

  - a maximal capacity for each IRIS was set (as above) but also a minimum of jobs, in order to avoid the simulation process of relocation totally emptying some IRIS. This minimum corresponds to the number of jobs in 2010 / 2.

- the second type of optimization allowed by the model is to find the minimum of jobs to optimally add to a given situation (jobs in 2010) in order to reach a given level of accessibility (the level of accessibility with the ROS in 2030). The logic corresponds to a minimization of the cost of change.

Accessibility was then calculated for these different optimization logics and for different transport scenarios: current travel times between and inside the IRIS, duration *1.15 and duration *1.3. These last two cases were intended to evaluate to what extent accessibility is directly dependent (proportional) on travel time.

The travel times between different IRIS were calculated between their centers, and those trips within the IRIS correspond to the mean of distances between a set of 50 random points (i.e. 2500 values). Table 1 gives the results for the simulations where, after the relocation process, each IRIS will have a minimum of 50% of the jobs forecast for 2030 in order to avoid to totally emptying any IRIS. Note that the results followed the same logic without these constraints, with a consequent increase of 10% on average in accessibility gains.

Table 1. Accessibility to jobs for different scenarios of jobs relocation

	Maximization of the mean accessibility by relocating the jobs planned for 2030											
	Reference scenario : accessibility in 2030 with the ROS without optimal relocation. Accessibility = 124.92 * 10^6											
N° Scenario	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**
Presence of the ROS	*No ROS*						*With ROS*					
Limitation of the capacity of Iris to host jobs	*Jobs 2010 * 1.5*			*Population 2030 per IRIS*			*Jobs 2010 * 1.5*			*Population 2030 per IRIS*		
Speed scenario	*Current transport duration*	*Duration * 1.15*	*Duration * 1.3*	*Current transport duration*	*Duration * 1.15*	*Duration * 1.3*	*Current transport duration*	*Duration * 1.15*	*Duration * 1.3*	*Current transport duration*	*Duration * 1.15*	*Duration * 1.3*
% of jobs required for the relocation process to maximize the mean accessibility and to fullfill the constraints	24 %	24 %	24 %	34.35 %	34.35 %	34.35 %	24 %	24 %	24 %	34.35 %	34.35 %	34.35 %
Accessibility before the relocation process ($x10^6$)	**122.55**	114.6	107.28	122.55	114.6	107.28	**124.92**	117.07	109.84	124.92	117.07	109.84
Accessibility after the relocation process ($x10^6$)	**148.31**	139.14	130.67	152.63	143.37	134.76	151.03	141.98	133.61	155.32	146.2	137.69
Gain (%)	21.02	21.41	21.80	24.54	25.10	25.61	20.90	21.27	21.64	24.33	24.88	25.35

4. Ensuring a worthy accessibility potential without a speed increase : it is possible

4.1. Maximizing mean accessibility

The comparison of accessibilities for the different scenarios demonstrates that it is possible to reach a good level of accessibility without the ROS. For example (scenario 21), whereas the ROS will lead to an increase of 2% in accessibility (from 122.55 without ROS to 124.92 with the ROS), optimally relocating 24% of the jobs forecast for 2030 increases the accessibility by 21% (148.31). The threshold of 24% corresponds to the maximum number of jobs available for relocation in order to meet the limits set regarding the minimum and maximum number of jobs per IRIS wanted after relocation (maximum 1.5 * number of jobs in 2010; minimum 50% of the jobs in 2010). Without these constraints, the gain exceeds 30%. Spatially, coupling the relocation tool and a geographical information system enables the results to be mapped. For example, in figure 2 it can be seen that the maximization of the mean accessibility on the basis of the jobs in 2030 improves the accessibility of the most central IRIS (figure 2, right) where the majority of jobs are relocated to the detriment of peripheral IRIS.

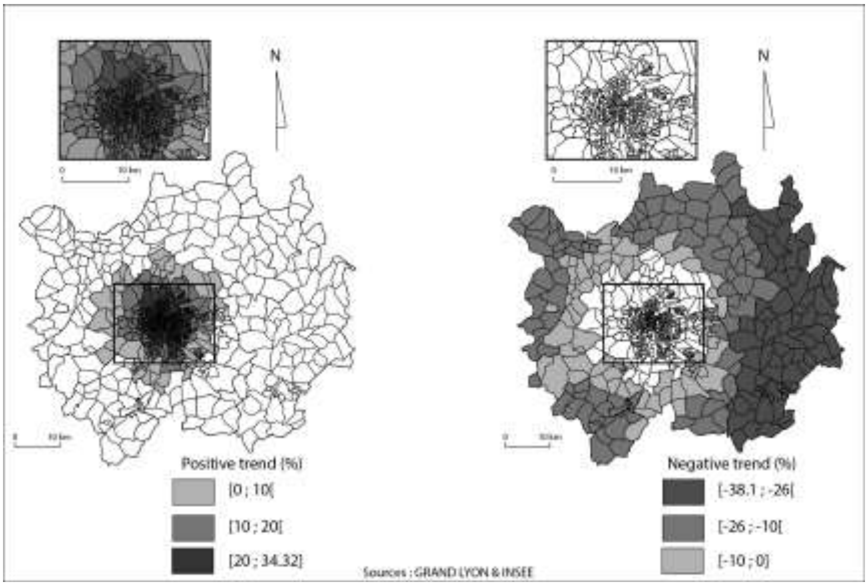


Fig. 2. Change in accessibility (%) to jobs in 2030 with and without optimal relocations

On average, the job relocation process improves accessibility by around 23%, and even more if there are fewer constraints on the capacity of IRIS to host jobs (which allows more jobs to be relocated). The higher values of accessibility are obtained when the capacity of IRIS for jobs is equal to the forecast population of 2030, which gives the possibility to relocate 35% of the jobs. We can also notice that there is no direct proportionality between the increase in travel time (see the speed scenarios) and the corresponding decrease in accessibility. Both with and without relocations, the decrease in accessibility is only 6% when the travel times are multiplied by 1.15 and 12% for a multiplication by 1.3. It appears also that the lower the travel speed, the more efficient the relocation process, in terms of accessibility comparison before/after, even if the differences remain low. Finally, it can be seen that the relocation process is able to increase accessibility even if the ROS is built (scenario 27). Thus, relocating 24% of the jobs in 2030 with the ROS increases the level of accessibility reached with the ROS by 20%. Logically, the higher value of accessibility (155.32) is reached when the impacts of the ROS are combined with the relocation process with low constraints (scenario 30).

These first results prove that it is theoretically possible to exceed the level of accessibility to be provided by the ROS in 2030, only by relocating jobs. However, this raises a question of scheduling. It appears difficult (but not impossible) to relocate between 25 and 33% of the jobs in the time span corresponding to the building of the ROS (particularly for jobs which are not included in the tertiary sector of employment), in particular because urban planning and forecast documents cover a period longer than the duration of such a project. Thus, the next section presents the second logic of relocation, which aims at minimizing the effort by minimizing the quantity of resources to add to a given situation in order to reach a target in terms of accessibility.

4.2. Minimizing the required relocations to reach the level of accessibility in 2030 with the ROS

Given that relocating one third of all jobs may be too expensive or difficult, the second logic of relocation allowed by the model was tested. The idea is to minimize the number of jobs to add and to locate optimally in order to reach a given level of accessibility (in this case for 2030 with the ROS) starting from the current (2010) job situation. The results show that the previous findings remain valid, that is to say that worthwhile levels of accessibility can be achieved without the ROS. For example, starting from the job locations in 2010, optimally locating 97,738 new jobs is enough to reach the level of accessibility to be provided by the ROS in 2030 (with a capacity of IRIS to host jobs limited to 1.5 * number of jobs in 2010). If the locations of all the 179,296 new jobs planned for 2030 are optimized starting from the situation in 2010, this leads to an increase of 11.5% of the level of accessibility provided in 2030 by the ROS. These results are important in terms of operational planning, because such optimal locations are highly possible in the medium term, unlike relocating one third of jobs (see 4.1). Choosing suitable locations for new jobs is indeed “free”, and depends “only” on suitable planning documents. Spatially, the optimally added jobs are located in the small IRIS in the center of the city because they are the most accessible in terms of network distance, and because they are small and numerous. This means that for a given distance, they have a lot of neighbors within easy reach. It is also due to a study area partitioning effect, as the more peripheral the IRIS, the rarer their neighbors for a given distance, and so the less attractive they are for the relocation algorithm.

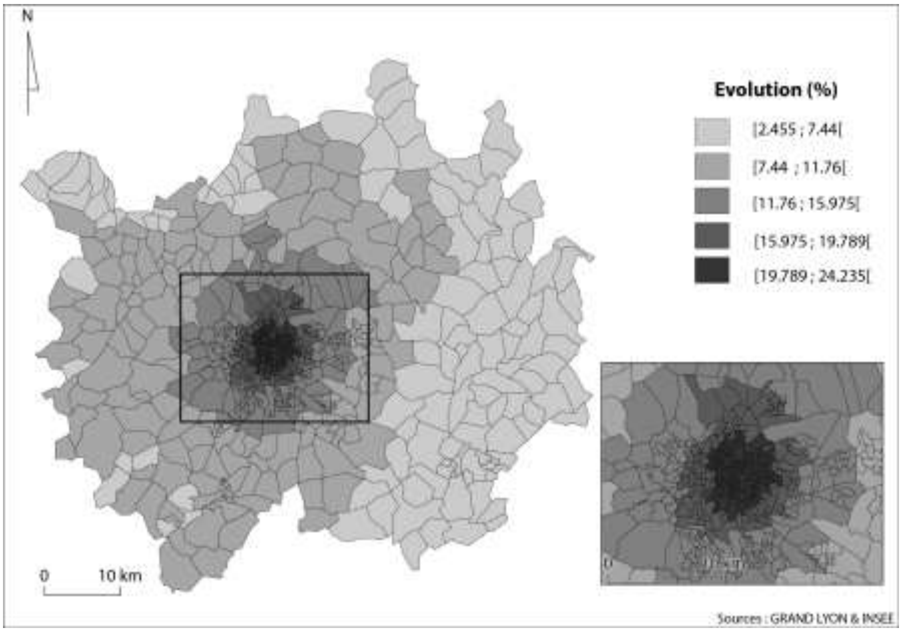


Fig. 3. Change in accessibility (%) to jobs 2010 with and without the addition of 97,738 optimally located new jobs in order to reach the level of accessibility to be provided in 2030 by the ROS

5. Improvement of the relocation model

In order to limit this issue of the location of the new jobs mainly in the center of the study area, different solutions can be designed. It is possible to collect data for a larger area in order to consider each IRIS in its real spatial context. It is important to emphasize that this problem is not only technical, but also a recurrent problem for urban planning. Very often, the planning is carried out depending on the administrative territories in which planners can legally apply their competences, rather than according to functional territories in which people live and go about their daily tasks. This can lead to any factors outside the administrative territory being ignored. Another possibility to limit this “center effect” would be to consider a homogeneous partitioning of space, for example as a grid with square cells. In this case, issues would concern the preparation of appropriate data for the simulations. It is necessary to disaggregate the data for peripheral IRIS at a finer scale, and on the contrary to aggregate the data for the smaller IRIS in the center, with processes to ensure the quality of the data in both cases. In this study, rather than testing these different possibilities mainly related to a problem of data quality, two other methodological possibilities (which follow the same logic) are described to limit the impact of the center effect and one more thematic option:

- the first methodological option consists in adding the population of each IRIS to the relocation algorithm. In this case, the mean accessibility for the centers of the IRIS is no longer optimized, but the population with a good level of accessibility is maximized. The accessibility for an IRIS is then weighted by its population. In this case, the logic is differs from before, as we are no longer in the logic of the city as a potential. Rather than maximizing a theoretical potential of accessibility to jobs in each place, the current spatial distribution of the population is taken into account in order to maximize the level of accessibility.

- the second methodological option is similar to the use of a homogeneous partitioning of space. In this case the area of the IRIS is taken into account, and the algorithm aims to maximize the fact that each square meter of the territory can benefit from the highest level of accessibility. Therefore the accessibility weighted by the area of the IRIS is maximized. To compute this option, it was considered that the level of accessibility is evenly distributed throughout the IRIS, and corresponds to the level measured for the center of the IRIS, even if this is not the case for larger IRIS where inevitably some parts are less well connected to the main road network.

- lastly, the "thematic option" consists in considering land prices per IRIS (data source: Grand Lyon) in the process to favor the relocations to the areas with lower land prices (usually in the outskirts).

The first and second options which follow the same logic are discussed in sub-section 5.1, while sub-section 5.2 deals with the land prices option.

5.1. Relocations weighted by surface or population

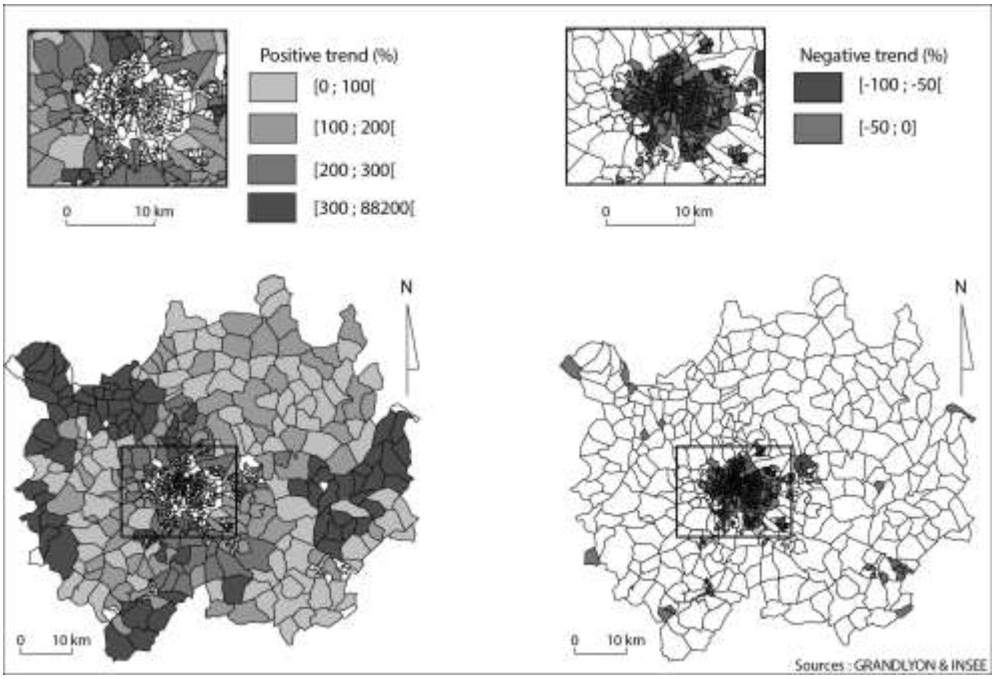
Previously, the relocations were calculated in order to maximize the total accessibility by choosing areas with the highest αj (3). With this alternative the principle remains the same but in order to take into account the area *vs* the population of a spatial units *i* in the relocation process, αj is multiplied either by the area or by the population of *i*. Note that multiplying αj by the area or by the population is the same operation as multiplying the standard gravity accessibility by the same values. Hereafter, new accessibility values resulting from considering the IRIS area will be called « area-weighted accessibility», whereas « population-weighted accessibility» will refer to population based values. To find the relocation optimizing these accessibility levels, the relocation algorithm is used identically except that each αj is multiplied by the area or by the population. Obviously, if jobs are relocated according to the weighted αj (by population or area), then the "standard accessibility" computed previously with the new locations will no longer be optimized, and may even decrease.

The table below gives the results for the relocation of the jobs in 2030 without ROS and for the same constraints as previously mentioned (4.1) regarding the maximum and minimum for jobs per IRIS. It must be remembered that the values of accessibility for the different types of maximization are not inter-comparable, because they are not in the same unit of measurement. However to enable comparisons, the corresponding "standard gravity based accessibility" levels have been computed for each spatial configuration obtained with the different methods of maximization.

Table 2. Accessibility to jobs 2030 for different types of maximizations

	Accessibility before relocation	Accessibility after relocation	Gain	Corresponding evolution for the standard gravity based accessibility	Percentage of jobs relocated
Maximization of the mean accessibility	$1.22 * 10^6$	$1.48 * 10^6$	21%	21%	24%
Maximization of the level of accessibility for the population in 2030 (accessibility weighted by the population of IRIS)	186,637,713	226,654,029	21.44%	15.80%	23%
Maximization of the level of accessibility of each square meter of the territory (accessibility weighted by the area of IRIS)	68,387,138	83,288,928	21.80%	-8.70%	18%

It appears that in each case the relocation process improves the area-weighted accessibility, as well as the population-weighted, by approximately 20% for the relocation of less than 25% of jobs. However, if the maximization of population-weighted accessibility induces an increase in the corresponding standard gravity accessibility, this is not the case for the maximization for the area-weighted accessibility. In the latter case, numerous jobs are relocated to the periphery of the city in order to balance the large size of its IRIS and their low accessibility due to their location on the outskirts of the urban conglomeration (fig. 4). The consequence is a decrease in the gravity accessibility standard measure, which greatly depends on the level of accessibility of the most central IRIS.



Sources : GRANDLYON & INSEE

Fig. 4. Relocation of jobs according to a maximization of the level of accessibility for each square meter of the territory

5.2. Relocations taking land prices into account

In order to consider land prices in the relocation process, two different approaches are possible. In the first, we no longer simply try to increase accessibility, but also to locate jobs in the cheapest sectors. The aim is therefore to maximize the ratio "accessibility / landPrice^a". The higher the exponent "a" in the denominator, the more important land prices are in the localization logic, to the detriment of accessibility. This approach is similar to relocations weighted by area or population (5.1), so the results will not be developed. Briefly, it consists in weighting αj, the constant generating accessibility for a zone j, by the inverse of its land price and then to relocate jobs according to βj with $\beta j = \alpha j / \text{landPrice}_j^a$ rather than according to αj.

In the second method, land prices are only used to drive the priority for the location choices. It is assumed that the cost of relocation is proportional to the land price of the destination zone. For a partial relocation, the objective is to promote the less costly relocations. In this method, a "classical" complete relocation is first simulated, i.e. land prices are not initially taken into account, in order to obtain the list of the areas destined to receive or to lose jobs. Then, x jobs are taken from the list of areas which will lose jobs (sorted by αj as in a classical relocation), and relocated in priority to the zones with a high index βj. Until now, the number of jobs available for relocation has been the constraint limiting relocations. Using this approach, this constraint may be replaced by a financial parameter (a budget).

Figure 5 gives a comparison between the results from the "classical" relocation method (broken line, figure 5) and the method with land prices (solid line). These curves were both generated for a complete relocation of jobs in 2010 without the ROS. It can be seen that the full optimal relocation remains the same for both methods, as land prices only change the priority of relocations. It also appears that the curves are very close (with a parameter *a* set to 1), even if the increase in accessibility is obviously lower at the beginning for relocations taking land prices into account. Overall, the impact remains low. Thus this method may be useful if the resource needs to be relocated little by little, starting with the most profitable relocations, while keeping the final optimal situation as a goal. If the user of the tool wants to consider other (more qualitative) constraints in the relocation process, it is possible to use the indexes βj and αj, which are known for each spatial unit, as a basis for decision making.

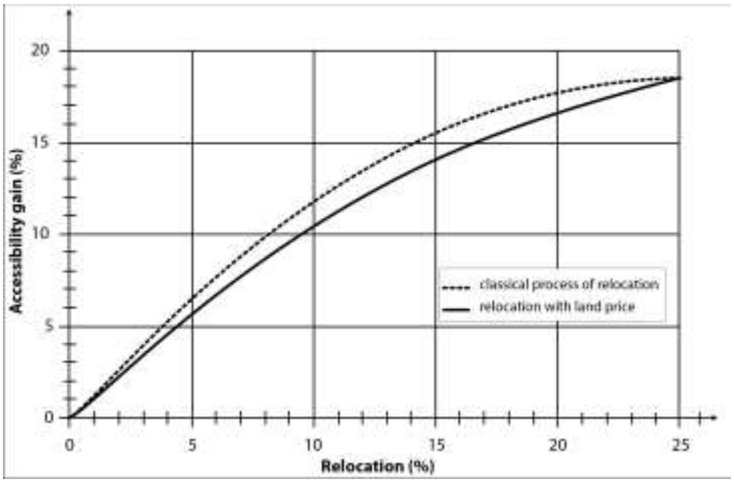


Fig. 5. Accessibility gain according to the percentage of jobs relocation for the classical and for the land prices methods

6. Conclusion

Accessibility depends on speed but also, and above all, on location. This is precisely what this work intends to prove, through the case of Lyon’s Ring of Sciences and the computation of accessibility to jobs. It has been demonstrated that the increase in accessibility to jobs (2%) due to this possible new road infrastructure bears no comparison with the possible gains provided by job relocations (around 20%). In the same vein, simulations prove that there is no proportionality between travel speed and accessibility, as the impacts on accessibility of increases in travel time remain low. Thus, rather than infrastructure building, job relocations seem to be a more powerful lever in increasing and redistributing the level of accessibility. Logically, the greater the freedom in the relocation process, the higher the increase in accessibility levels.

From a spatial point of view, the maximization of gravity-based accessibility by jobs relocations tends to favor central areas. This is due to the fact that as the road network is very dense and relatively homogeneous in the study area, it consequently gives a crucial importance to Euclidean geometry in the calculation of accessibility. Central locations remain the most accessible, which is not always the case with less dense and anisotropic road networks. However, if planners choose to avoid this type of central concentration promoted by the relocation process, it is possible to change the logic of optimization by maximizing the population with a good level of accessibility, or by maximizing the level of accessibility of each square meter of the territory. Both options boost peripheral zones for job relocations in order to balance the importance of Euclidean geometry. Another solution to avoid job concentrations in central areas is to integrate relocation cost in the process (in this case through land prices), which favors the periphery where prices are generally lower. For further work, a suggestion would be to change the optimization logic by maximizing the mean accessibility and at the same time to target territorial equity, by trying to minimize its variance between the IRIS. So far, this possibility remains technically difficult.

Beyond our results which may be criticized from a thematic point of view regarding for example the thresholds chosen for the IRIS capacity to host jobs, or the calibration of gravity based accessibility, the most important point concerns the approach implemented and in particular the *Ac-Rel* tool. It offers great and original possibilities for accessibility planning, linking in an exploratory perspective transportation speed, locations and accessibility. *Ac-Rel* allows the enhancement of the critical contribution of locations to accessibility. With locations often considered as given it is rarely taken into account. This explains why increasing speed is considered as the main lever to improve accessibility. In other words, planners generally prefer to act on a city’s functioning rather than on its spatial structure.

Linked to this heuristic perspective, *Ac-Rel* may also contribute to a review of the road infrastructure evaluation process. Instead of trying to evaluate the impacts of a new infrastructure (in terms of time saving or in a multi-criteria perspective), the idea is to explore conditions in which it would be possible to obtain the same benefits (in terms of accessibility) by optimally (re)locating a resource (i.e. jobs) rather than by building roads. However this use of *Ac-Rel* for infrastructure evaluation raises many questions. It is necessary to know the cost of the planned infrastructure (not the case for the ROS) and to be able to evaluate the relocation cost of jobs depending on their nature, in order to estimate if, for a given level of accessibility, it is less expensive to relocate jobs or to build the infrastructure. This assessment of the relocation costs appears to be very difficult because it varies depending on job type and geographical context. Moreover, it is necessary to determine jobs which can actually be relocated: their types, people's acceptance level, and the time horizon. In terms of temporality, a major difference between the building of an infrastructure and a relocation process is that the span of the achievement is known for the first option, but is much more difficult for the second. Lastly, and certainly the main issue, job relocation and transport infrastructure decision-makers are in different organizations, each with their own views and interests, and working together will require a challenging dialogue.

All these difficulties contribute to explaining why planners, perhaps looking for a familiar and easy solution, prefer to work on speed rather than on (re)location in order to improve accessibility. However, the problem is in fact much wider and raises the issue of the possible conditions for a suitable planning process in the medium term. In France, for example, agglomeration planning documents are established for 15 or 20 years. Accessibility planning through (re)locations rather through speed thus appears to be difficult to implement, yet possible. To conclude, *Ac-Rel* appears to be a heuristic tool, and potentially an empiric tool for infrastructure evaluation, which demonstrates that in the distance, speed and time trilogy (Banister, 2011) distance and therefore locations have considerable importance. *Ac-Rel* may help to provide high levels of accessibility decoupled from speed and its associated use of the private car, for a more sustainable future.

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