SUSTAINABLE URBAN MOBILITY AND LAND USE AND TRANSPORT INTERACTION MODELLING: EXAMPLE FROM THE SIMBAD PROJECT

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ABSTRACT

This communication focuses on the representation of different issues related to sustainable urban mobility in LUTI models. It is based on developments in the SIMBAD project (SImuler les MoBilités pour une Agglomération Durable - Simulating mobilities for a sustainable urban area), which applies a LUTI model to the urban area of Lyon, France.
Two simplified urban sprawl scenarios (diffuse versus multipolar) are used to provide support for the implementation of sustainable mobility indicators proposed in as part of the SIMBAD system. The analysis carried out helps to show the wealth of results provided by these models and the expanded vision they can provide in the field of sustainable development for an urban area.

Keywords: LUTI model, sustainable mobility, simulation, urban sprawl, sustainable development indicators

INTRODUCTION

The topic of sustainable development is an important focus of discussions on local public policies. LUTI models (Wegener, Fürst, 1999; Simmonds et al., 1999; Waddell et al., 2001, Hunt et al., 2005) are used to provide a better vision of the long-term issues involved in developing transport networks and therefore provide excellent support for thinking on sustainable development. In the case of France, which provides the context for the experiment described in this paper, many projects have gradually emerged over the last fifteen years (Antoni, 2010), with, for example, applications of the UrbanSim model in Paris and Lyon (De Palma et al., 2005, Nicolas et al. 2009), Tranus in Grenoble (Dutta et al., 2012) or the development of innovative tools such as the multi-agent model MobiSim in Besançon (Antoni et Frankhauser, 2010) and the general equilibrium model Pirandello (Delons et al., 2009).

Besides methodological thinking on the relevance of the tools developed and implemented, significant space needs to be given over to the outputs of models and how to organize them to account for the sustainable development, or lack of it, of an urban transport system.

How can one represent the various issues related to sustainable urban mobility and how can one highlight the different indicators to make the results intelligible and interesting for those involved in local public policies? This paper proposes an answer to this question by showing how it was handled in the case of the experiment with the SIMBAD model developed in Lyon. It is broken down into three parts:

- ✓ The first proposes a system of sustainable mobility indicators that can be integrated into a LUTI model - in this case the SIMBAD model applied to the Lyon urban area.
- ✓ Secondly, we present two simplified urban development scenarios and describe their consequences in sociodemographic and mobility terms.
- ✓ The final part spotlights the sustainable mobility indicators proposed, showing the impact of the scenarios on the sustainability of the transport system.

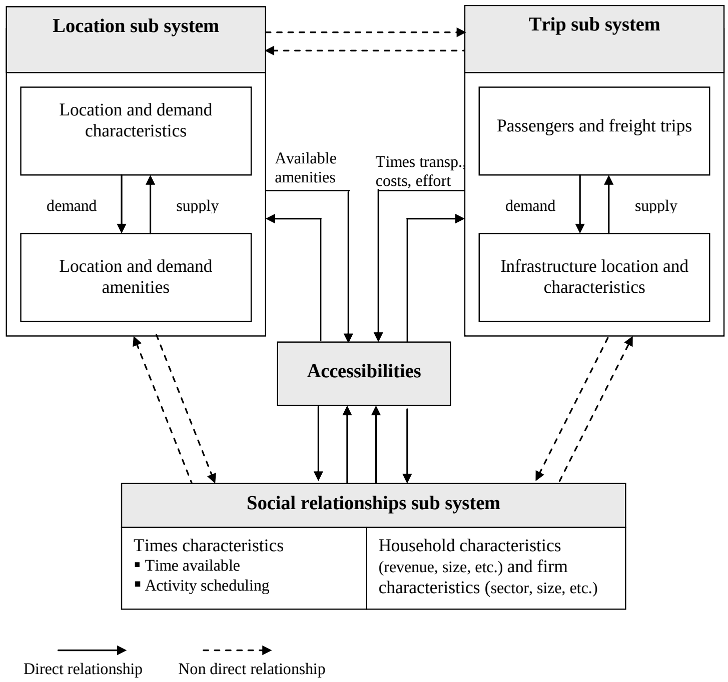
SIMBAD: TAKING THE SUSTAINABLE DEVELOPMENT CONCEPT INTO ACCOUNT IN PROSPECTIVE TRANSPORT & LAND USE MODELS

We first present the background of the sustainable mobility indicators that have been chosen to take. A second subpart is the dedicated to a presentation of the SIMBAD model.

What indicators for sustainable mobility?

Sustainable development remains an open concept that can convey values and cover extremely different social projects. Today, in general, for an approach to be considered as integrating a sustainable development concern, it must first seek to cover the short and long term, both locally and globally, and simultaneously take into account the economic, social and environmental aspects of the issue it relates to (Theys 2000; Zuindeau, 2006). Other meanings exist (for example, see reviews by Gudmunsson, Hojer, 1996, Giorgi, 2003, on transport; Pezzey, Toman, 2002, on economics; Hardi, Muyata, 2000, Vivien, 2008, for a more general view), often with a greater focus on a specific aspect (economic or environmental sustainability, for example), but we have preferred the meaning that appears both the most open and the most in phase with the major concerns of our era (Verry, Nicolas, 2005). The goal is to demonstrate that, from an operational perspective, to evaluate the long-term impact of an urban transport policy, an analytical tool that coherently uses economic, environmental and social indicators can be made available (Joumard, Nicolas, 2009). It also advocates in favour of open evaluation approaches that avoid the limitations of theories that

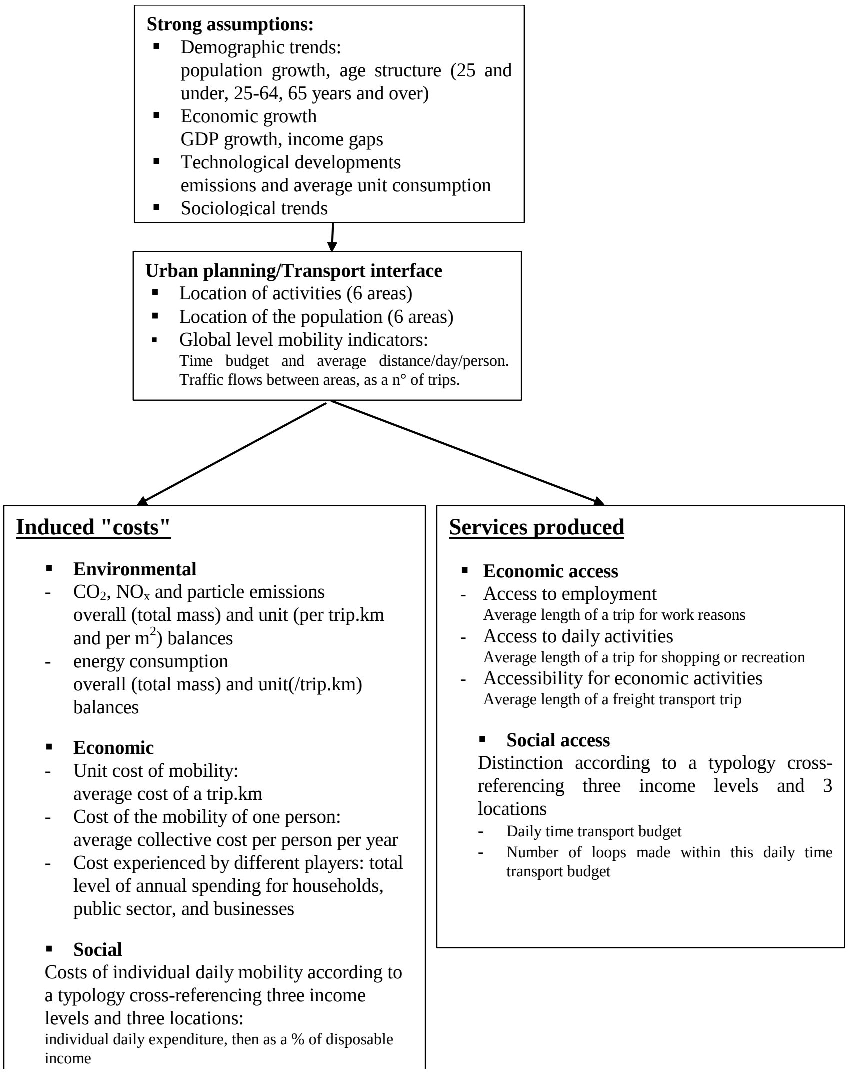
may be very coherent from the perspective of an internal logic, but are often too closed in to enlighten public decisions that are politically relevant (Costanza et al., 1997).
The thought process adopted to implement sustainable mobility indicators in SIMBAD (Verry, Nicolas, 2005) is based on the representation of interactions between transport and land use in three systems (localization, mobility and social practices) (Bonnafous and Puel, 1983): (1) the localization subsystem refers to the various uses of land and their occupation of space; (2) the travel subsystem is composed, first, by the flow of people and merchandise and, second, the transport system that physically allows for the expression of this mobility; (3) the social practices and relations subsystem, which includes daily activities, is tied to the way society operates.



Source: Verry and Nicolas, 2005, adapted from Geurs and Van Eck, 2001
Figure 1: The transport-land use system via the accessibility concept

The travel subsystem is favoured in SIMBAD, as it is its impacts that are evaluated. However, the dynamics and long-term changes of this subsystem can only be perceived through its interactions with the two other subsystems (Wegener, Fürst, 1999). The key concept that distinguishes this interaction is accessibility, which is characteristic of the service provided by a travel system within a given spatial and social configuration (Geurs and Van Eck, 2001). Improving accessibility is one of the main objectives of all transport policies, but it is difficult to characterize as it combines features related to space, time, the location of activities, transport systems and social practices. The relationship between accessibility and the three components of the urban system is represented in the diagram set out below (Figure 1: The transport-land use system via the accessibility concept).

Figure 2. The indicators characterizing the costs and services of the transport system



Source: from Verry et Nicolas, 2005

The indicators therefore relate to services provided and the cost and disturbance of mobility within urban settings, with a breakdown into three dimensions: economic, environmental and social (Verry and Nicolas, 2005). To demonstrate the changes in services provided by the system, we have adopted the evolution of the average accessibility of households to employment and shops, as well as, for businesses, average accessibility to economic activities. To examine social aspects, a more precise study is conducted based on their revenue (divided into three classes) and location. In terms of costs, (1) the environmental impact is measured using the evolution of CO2 emissions, NOx, particles and hydrocarbons - local and global air pollution is therefore favoured here, and other types of impact, such as noise or the occupation of space have not been included in this first version, although they may be in the future; (2) the financial cost of the transport system is established based on mobility accounts, with an estimate of the expenditure of public authorities, households and businesses (CERTU, 2005); (3) from a social perspective, the cost incurred by households is measured using the relative portion of revenue dedicated to daily travel and breaking the households down, like above, according to revenue and location (Verry and Vanco, 2009). The final indicators can be presented in the Figure 2.

Application to the urban area of Lyon

To measure the evolution of these sustainable mobility indicators, the Simbad project ("SImuler les MoBilités pour une Agglomération Durable" ie "simulating mobilities for a sustainable agglomeration") has been developed in France by Laboratoire d'Economie des Transports. An initial version of the model was created (Nicolas et al., 2009; Nicolas et Zuccarello, 2010) in partnership with Lyon's Agence d'Urbanisme ("urban planning agency") with the support of Informatique Innovation in the context of financing from the Research Department of the French Ministry for Ecology, Sustainable Development, and Energy (MEDDE) and the French energy agency (ADEME).

The platform thereby developed proposes a modelling of the travel system in an urban area and its interactions with urban planning. Designed on the scale of an urban area's services and working area, its objective is to allow for a simulation of various transport and land use policies while projecting their impact over the three dimensions of sustainable development, taking into account the ties between them. The approach is strategic and provides an overview of the impacts of varying policies on the scale of the urban area, more so than specific projects on a finer scale.

It relies on a traditional modelling of the transport system and its interactions with the localization system. A platform was therefore designed to link a number of major steps together, each one designed as a specific module: "localization of households and businesses" ⇨ "mobilities" ⇨ "traffic distribution and assignment", over a cycle of 25 one year periods (Nicolas et al., 2009). The different "transport" modules lead to generalized times that allow for an estimation of accessibility indicators, used in household and activity localization modules.

- ✓ Two modules represent the interactions between transport and the location of business activities, on the one hand, and residences, on the other. The UrbanSim platform (Waddell, 2001) is used there, with a discrete choice approach for the modellisation;
- ✓ Freight transport in urban areas is taken into account via the integration of the FretUrb model developed by Laboratoire d'Economie des Transports;
- ✓ An original module to generate individual mobility was developed based on a random micro-simulation of mobility behaviours by classes of individuals;
- ✓ This module extends to distribution and modal breakdown phases, which distinguish household revenues (20% for the lowest, 60% for the average, and 20% for the richest), and lead to three OD matrices;
- ✓ The various freight and household matrices are assigned using the PTV Visum software and according to the "multi-class" process, thereby providing details on who is travelling where and evaluating related emissions and costs;
- ✓ And, finally, an integration interface was put in place to manage all the modules and have them iterate annually over a 25 year period.

The field of application adopted was the urban area of Lyon, in particular based on INSEE data for 1999 and 2005 (general census of the population, SIRENE files for businesses), on the one hand, and, on the other, household surveys on local mobility (1995 and 2006). This choice was selected due to the team's availability and broad knowledge of the field data, and also because local players were interested in participating in applied research such as SIMBAD.

From a methodological standpoint, a number of choices were made in relation to the tools used to put this organization in place. First, the traditional four step structure was adopted for the model. It benefited from innovations and developments resulting from LET work on generation, distribution and modal share (Cabanne et al. 2000; Bonnel, 2004; Gitton, 2006), and similarly for traffic related to freight reflected in the FRETURB model (Routhier et Toilier, 2007).

The SIMBAD platform is now completed, with all its modules estimated and providing satisfactory results. The four stages of the modelling chain have been tested using Lyon travel surveys dating from1985, 1995 and 2006, and modelling of the transport networks at these same dates (Cabrera, 2010, 2013). It appears that this "transport" component of the SIMBAD platform provides relatively robust results, as long as we remain at an aggregate level. A strategic analysis of the impacts of a transport policy and urban planning is therefore perfectly possible, which confirms the initial ambitions of the model. A thesis is underway to provide a nested logit structure for the household location model, first favouring the choice of a type of zone before determining the specific location cell (Aissaoui et al., 2012).

An overall assessment of the entire system process is now under way as part of the CITIES project (http://www.multiagent.fr/CITiES). Similarly, a first set of consistent and contrasting scenarios for the changes in urban structure and the travel system is being developed within the VILMODES project [1].

AN EXAMPLE OF TWO FIRST URBAN SPRAWL SCENARIOS

The SIMBAD platform is then still under development. But it is already possible to apply some simple scenarios to show which kind of results can be attended, giving the opportunity to discuss the relevance of the chosen indicators to assess the sustainability of the transport system and its interactions with the urban development.

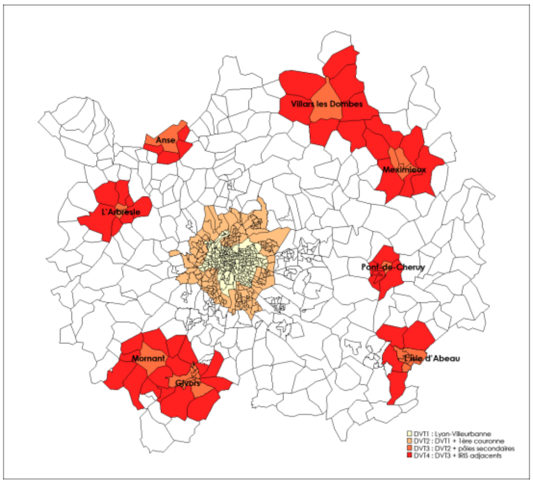
Two simplified urban sprawl scenarios

To this end, two simplified urban sprawl scenarios have been implemented. Both consider an increase of 21 % in the population (27 % of households) between 1999 and 2025, which corresponds to the INSEE median prospective for the Lyon urban area. They differ on how the new housing built to accommodate the additional households is divided up within the urban area.

[1] http://tempsdubilan-predit4.org/wp-content/uploads/2013/02/8-VILMODes-ville-mobilite-durable-evaluation-simulation-Antoni.pdf

- ✓ The first, entitled "diffuse urban sprawl", considers a homogeneous sprawl over the whole area outside the two cities Lyon (centre) and Villeurbanne. New homes are built in each area in proportion to its surface.
- ✓ The second, entitled "multipolar development", distributes these new homes only in the 1st ring and around peri-urban centres identified as centres of development preferred by the Lyon authorities. The map below shows the areas of residential development selected in this way.

Figure 3: Urban development areas in the multipolar scenario

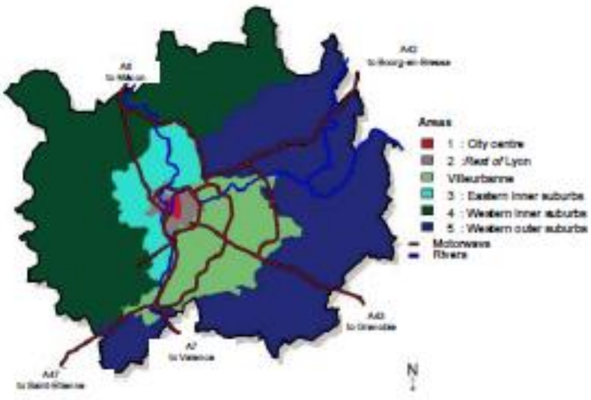


The other assumptions are common to both scenarios. Employment grows by 10% to keep the same employment and unemployment rates in the working population as a whole over the 25 years of the simulation. Economic activity continues to expand towards the tertiary sector, at the expense of industry. The development of transport networks follows the investment programme planned for the Lyon urban area, both for road infrastructure and for public transport. Finally, for these first simplified scenarios, we assume constancy of the various components of transport costs.

All results are based on partitioning into six areas as shown in the map below. Depending on what it is desired to show, they can be grouped according to an East/West logic (Lyon-Villeurbanne, East, West) or radiating in concentric circles (Lyon-Villeurbanne, with the 1st ring corresponding to the administrative area covered by the regional integrated development plans (*Schéma de Cohérence Territorial)*, and the 2nd ring corresponding to the rest of the urban area).

The consequences of these two scenarios on the model results can first be expressed in terms of changes in the composition of the population in the area (number of people, age, income) and changes in travel conditions in the networks. These initial points are examined in the following sub-sections.

Figure 4: Division of the urban area into six zones



Source: SIMBAD output

Demographic changes differentiated according to the scenario

By construction from the two scenarios, the central Lyon-Villeurbanne hub undergoes no new building work, and its population is almost stable, moving from 560,000 to 550,000. This slight decrease (-2%) is related to the aging of households, whose average size decreases among seniors. The overall growth of +21% of the population is then distributed over the rest of the urban area. The first significant difference between the two scenarios can then be observed:

- ✓ In the diffuse urban sprawl scenario, this growth is nearly uniform across the area.
- ✓ In the multipolar scenario, it is concentrated on the 1st ring and the secondary hubs and their adjacent IRIS zones: these areas have an average population growth of 76%, while the rest of the area empties somewhat, losing 7% of its population between 1999 and 2025.

Two other differences can also be highlighted in these population volume changes. The first is that the preferred development of the 1st ring in the "multipolar" scenario limits urban sprawl, which is much more noticeable in the "diffuse" scenario: the share of the 2nd ring is 24% of the population in 1999. It remains stable in the "multipolar" scenario, while it rises to 29% in the "diffuse" scenario. Moreover, the "multipolar" scenario results in a balance between East and West in the urban area, which represent 36% and 35% of the population respectively in 2025. In contrast, the "diffuse sprawl" scenario maintains the initial discrepancies and the East still weighs greater than the West (38% against 34%).

Different attractions between centre and suburbs in terms of age and household activity

SIMBAD also shows two opposed forms of location logic depending on the age of the head of the household. Whatever the scenario, older households tend to prefer the centre, while younger ones set up home in the suburbs (Table 1).

This observation about the spatial structure based on age affects the changes in the proportions of individuals in employment in the urban area, which then acts on the location and nature of travel generated.

First, the proportion of households whose head is in employment drops in the 25 years of simulation, in conjunction with the general aging of the population. It falls from 46% to 43% of households between 1999 and 2025. Moreover, the movement towards a concentration of older households in the city centre results in a decrease in the proportion of individuals in employment in this space: households whose head is in employment fall from 47% to 41% regardless of the scenario. In the 2nd ring, in contrast, the proportion of these households remains above the average.

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Table 1 - Distribution of households in the urban area based on the age of the head of the household

	Under 60			*60 and over*		
	1999	2025 diffuse	2025 multipolar	1999	2025 diffuse	2025 multipolar
Lyon Villeurbanne	0.72	0.57	0.57	0.28	0.43	0.43
1st ring	0.69	0.63	0.64	0.31	0.37	0.36
2nd ring	0.73	0.70	0.68	0.27	0.30	0.32
Average	*0.71*	*0.63*	*0.63*	*0.29*	*0.37*	*0.37*

Source: SIMBAD output

Income distribution: gentrification of the city centre and a balance between East and West

The scenarios do not appear to be segregating as far as location by income is concerned. In both cases, we can see both a slight trend towards a concentration of wealthy households in the Lyon city centre, and the beginnings of a balance between East and West of the city.
When changes in income structures are observed on a radial-concentric basis (Table 2), it can be seen that low-income households prefer Lyon-Villeurbanne (except the city centre which remains less accessible to them) and the proportion of these then decreases as they become more remote from the centre. Median households, however, have a preference for the 2nd ring, while the highest incomes are distributed evenly in spatial terms, except for the city centre where there are relatively more of them.

Table 2 - Distribution of the population according to household income and distance to the centre

	1999			2025 diffuse sprawl			2025 multipolar		
	low	*median*	*high*	*low*	*median*	*high*	*low*	*median*	*high*
City centre	0.18	0.52	0.30	0.17	0.49	0.34	0.17	0.50	0.33
Rest of Lyon Villeurbanne	0.23	0.58	0.19	0.23	0.57	0.21	0.22	0.57	0.20
1st ring	0.21	0.60	0.19	0.21	0.61	0.18	0.21	0.61	0.18
2nd ring	0.18	0.63	0.20	0.18	0.63	0.19	0.18	0.63	0.19
Total	0.20	0.60	0.20	0.20	0.60	0.20	0.20	0.60	0.20

Source: SIMBAD output

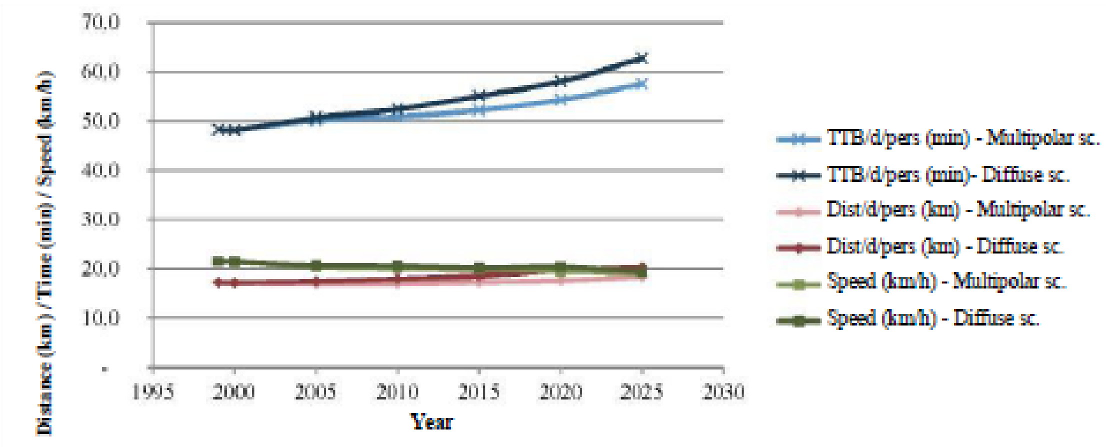
A restoration of balance between East and West of the urban area is also visible. In 1999, the traditional opposition of the Lyon area, between the wealthier Monts du Lyonnais and the plain of the less well-off East is well defined: in the East the population consists of 25% of individuals belonging to low-income households and 14% from wealthy households; in the

West, the proportions are reversed with 15 and 25% respectively. In both scenarios, there is a slight adjustment, with low incomes whose proportion falls from 25% to 23% in the East and rises from 15% to 17% in the West, while high incomes move in the opposite direction, outlining a movement eastward rising from 14% to 15%, and decreasing to the West from 25% to 22%. This movement is related to the assumptions of the proportion of social housing in new homes, which we have set at 20% homogeneously throughout the area.

Daily mobility greatly affected in the suburbs

These changes in demographics and locations of households obviously have a significant impact on general mobility indicators such as daily time budgets, distances covered or average travel speeds for all modes. Figure 5 below reflects these general trends in both scenarios.

Figure 5: Changes in general mobility characteristics in both scenarios



Since both scenarios envision a growth in the population from outside to the urban centre of Lyon and Villeurbanne, the distance travelled per person per day tends to increase as 2025 approaches. However, this increase is limited to 7 % in the multipolar development scenario, while it increases by 17 % in the diffuse sprawl scenario, which is less polarized and more strongly inclined towards the 2nd ring.

This increase in individual distances is added to the 21% of population growth, leading to saturation of the road network. Car speeds drop by about 20 % in both scenarios. Whatever the mode, the overall decrease in travel speed is about 10% over 25 years.

The combination of increased distances and lower speeds therefore leads to a marked increase in daily time budgets for residents of the urban area: 19% in the multipolar development scenario and 30% in the diffuse sprawl scenario.

This initial observation deserves a more detailed analysis in spatial terms. The increase in transport time budgets related to daily mobility of the inhabitants of the urban area varies significantly depending on where they live, because of divergent sociodemographic trends and different modal adaptations.

Table 3 – Changes in the main mobility characteristics according to the two scenarios

	1 999	2 025 Multipolar scenario	2 025 Diffuse scen.
Number of ½ loops per person			
Centre	2.6	2.7	2.7
1st ring	2.6	2.6	2.6
2nd ring	2.4	2.3	2.3
average	*2.6*	*2.6*	*2.6*
Distance per loop			
Centre	3,5	2.7	2.6
1st ring	7,0	6.3	6.4
2nd ring	11.5	15,3	16.3
average	*6.8*	*7,2*	*7,9*
Average speed			
Centre	11.9	9,1	8.8
1st ring	20.3	15,6	15,1
2nd ring	39,5	35,6	32.1
average	*21.5*	*19,4*	*19,2*
Car speed			
Centre	24.3		17,9
1st ring	30.5		20.2
2nd ring	47,1		34.1
average	*34.5*	*28.5*	*27,0*
Daily time budget			
Centre	*46.4*	*47,3*	*47,6*
1st ring	53,6	62.2	66.9
2nd ring	41.7	60.2	71.2
average	*48.3*	*57,5*	*62.7*

In the urban centre made up of Lyon and Villeurbanne, the overall drop in average speed (-16 to -13 % depending on the scenario) is driven by a drop in automobile speeds (about 25%) that encourages a modal shift towards public transport and walking. Moreover, the decline in the number of individuals in employment leads to a sharp decline in home-work loops in favour of other trip motives (they fall from 25% to 17% of loops made by the inhabitants of this area). As these loops are relatively longer, and since even in the centre they are easier to do by car, their decrease in number also facilitates the move from cars to other modes. So in this area, lower car speed is offset by the decrease in distance travelled, and the transport time budget per person per day remains stable (2.5% in both scenarios).

In 1st ring areas, the drop in speed is very clear (-25%), caused by a fall in speeds on the road network higher than elsewhere (about -33%) because traffic moving between centre and outskirts is added to local traffic. The distances are too great for walking to be a credible alternative (7 km on average between origin and destination), but a modal shift towards public transport, which is still present in this part of the area, can be observed.
Although to a lesser extent than in the centre, the loop length also tends to decrease (-13 % in the multipolar scenario and -8% in the diffuse sprawl scenario), whatever the reason. So the effects of the very sharp fall in speeds is partially offset by lower distances and slightly compensated for by the modal shift. However, these two counter-trends are too low to

prevent an increase in transport time budgets per person per day (+16 % in the multipolar scenario development, to +25 % in the diffuse sprawl scenario).

Finally, the 2nd ring areas outside Grand Lyon have several disadvantages in both scenarios and the current logic of the model. Firstly, their residents see their speeds decline (-10 to -19% depending on the scenario), once again because of the drop in road speeds (-20 to -28%), but without any possible modal alternative. Secondly, their daily distances increase greatly, because of the significantly increasing distance between origin and destination of the loops(+33 to -42% depending on the scenario), whatever the reason. So the transport time budget per person per day shoots up in the 2nd ring (+43 and 71% respectively).

IMPLEMENTING THE SYSTEM OF SUSTAINABLE MOBILITY INDICATORS

Now that the general trends of the two scenarios in terms of locations and movements has been established, what are their impacts in economic, environmental and social terms? The sustainable mobility indicators mentioned at the beginning of this paper will now be used to account for the results of the two scenarios.
So we will weigh in the balance, on one side, the services provided by the travel subsystem, expressed as access to urban space for the residents concerned, and on the other, the costs generated by operating this subsystem, translated as air pollutant emissions for environmental impacts and mobility cost constraints depending on the situation of the households for the social dimension (given that the module dealing with the overall economic cost of the travel subsystem is still to be developed in SIMBAD).

Changes in services rendered by the travel system

Clearly deteriorating economic access

In terms of economic efficiency of the transport system, three accessibility indicators were selected: access to employment, expressed by the average length of time an individual in employment in the urban area needs to go to work (i.e. the average time for half -loops whose main motive is commuting) access to daily activities, expressed by the average time for half loops going from home to shopping or recreational activities, and finally, access to economic activities, measured through the average movement of urban goods. These three indicators confirm what has just been observed:

- ✓ In both scenarios, the general reduction in speeds between 1999 and 2025 led to a deterioration of the city's economic performance.
- ✓ However, the multipolar development scenario limits the increase in individual daily distances, therefore limiting the decline in accessibility, while the diffuse development scenario promotes the increase and helps to reinforce deterioration.

Table 4 – Changes in economic access indicators

			Multipolar devt.		Diffuse sprawl	
		1999	2025	2025/1999	2025	2025/1999
Access to employment (½ loop for work reasons)	½ loop distance (km)	10.0	9,8	0.98	10.6	1.06
	Speed (km/h)	27,8	22,7	0.82	22,3	0.80
	½ loop time (min)	21.6	25,9	1.20	29,0	1.32
Access to daily activities (½ loop for purchases/leisure)	½ loop distance (km)	5,3	5,7	1.07	6.4	1.21
	Speed (km/h)	20.0	17,8	0.89	18.3	0.92
	½ loop time (min)	16.0	19,2	1.20	21.0	1.32
Access to economic activities (movement of goods)	Distance of a mvt (km)	15,7	13.7	0.88	14.0	0.89
	Speed (km/h)	38.4	30.7	0.80	29,6	0.77
	Duration of a mvt (min)	24.5	26.8	1.10	28.3	1.15

Source: from the outputs of the SIMBAD platform

In terms of access to jobs, table 4 shows that the speed of home-to-work loops is reduced by approximately 20% in both scenarios. Distance stability (-2 %) in the multipolar development scenario prevents an excessive increase in the duration of half-loops (+20 %). But these distances between home and work increase in the diffuse sprawl scenario (+6%), leading to a sharp rise in access-to-employment time (32%).
The same mechanisms lead to the same results in the case of access to daily activities. In both scenarios, the combination of increased distances (higher in the diffuse scenario than in the multipolar scenario) and lower speeds leads to the same deterioration in access time as in the previous case (+20 and +32 % respectively).
Finally, economic activities also suffer from this deterioration in accessibility, but to a lesser extent. Given the relocations now estimated by the model, the average range of goods movement tends to fall (about -11/-12 % in both scenarios), thus limiting the impact of decreasing speeds (-20 % for multipolar development, -23 % for diffuse sprawl). Deterioration of economic access remains limited, with an increase in the duration of movements of “only” +10 % in the first case and +15 % in the second.

For households, a decline in accessibility varying according to location and income

The social dimension of the services rendered by the travel subsystem is taken into account by distinguishing between households according to their location (Lyon- Villeurbanne / 1st ring / 2nd ring) and income (20% lowest incomes / 60% median / 20 % the wealthiest). For each of the nine sub-groups formed in this way, the level of daily mobility (expressed by the number of half-loops per person per day) was compared with the time spent travelling during the day (transport time budget related to daily mobility within the urban area).

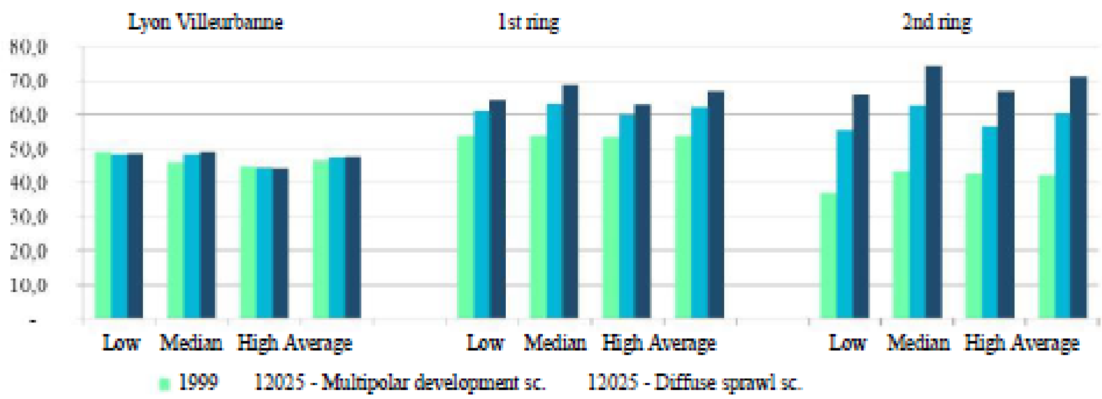
The model estimates the same level of mobility over the entire simulation period, regardless of the scenario. So the daily number of half-loops is 2.6 per person, without either income or the location of the household they belong to causing the figure to vary by more than 0.1 points or ± 4%, between the 9 groups of households and the 25 years of simulation. However, as we have already seen, physical access to urban amenities deteriorates sharply. The daily transport time budget in 2025 for a person to make the same number of loops as in

1999 increases by 19% in the multipolar development scenario and by 30% in the diffuse sprawl scenario.

Furthermore, analysis of transport time budgets by type of household reveals highly heterogeneous situations between those who live in the centre and in the outskirts, on one hand, and between income levels on the other.
The first source of inequity is spatial. While remaining constant in the centre, time budgets increase hugely in the 2nd ring. Widespread reduction in road speeds is not absorbed in the same way by modal alternatives from area to area. In addition, changes in the relative locations of populations and urban amenities, as well as the needs of these populations are changing unfavourably – as far as distances to be travelled are concerned – in the 2nd ring, and favourably in the centre.

These increases also reveal a tension between income levels. The most well-off systematically undergo a slighter increase than the others and the relative variations of distances and speeds act more to the disadvantage of median households in the 1st ring and modest households in the 2nd ring. Ultimately, it is the situation of low-income households in the 2nd ring that changes the most negatively and that of median households in the 2nd ring that is most worrying.
Finally, the multipolar development scenario, without providing a satisfactory result from the standpoint of equitable changes in transport time budgets, somewhat softens the situation with respect to the deterioration in the diffuse sprawl scenario.

The first set of indicators shows that the services rendered by the mobility sub-system deteriorate seriously, with more heterogeneity in the situations and the way they change depending on location and household income. Moreover, the multipolar development scenario gives less downgraded results than the diffuse sprawl scenario. What about the indicators that reflect the costs of this subsystem?
Figure 5: Changes in daily transport time budgets based on income and location - multipolar and diffuse scenarios



Source: from the outputs of the SIMBAD platform

Changes in costs incurred by the travel system

Contrasting changes in emissions depending on pollutants

Both scenarios are based on an increase by 21% of the population of the urban area in 25 years, with a proportional increase in the number of loops made. We have also seen that the average distance travelled per person per day increases due to changes in the urban structure, with +7% in the multipolar development scenario and +17% in the diffuse sprawl scenario. These extended distances also requires greater reliance on the car, and car traffic measured in vehicles.kilometre increases by 28% in the first scenario and 43% in the second. If we add the concomitant reduction in speed on the road network, all the necessary mechanisms seem to be set up to give a very strong increase in emissions. Only changes in vehicle characteristics can help to offset these trends, with a greater or lesser impact on pollutants.

For the moment, we have chosen estimates of emissions of air pollutant levels to represent environmental impacts, and we will use NO_x emissions here to account for local issues and CO_2 emissions for global issues.

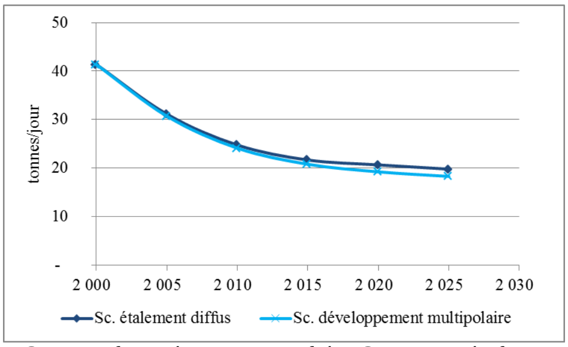
NO_x emissions falling significantly

As far as NO_x emissions are concerned, technological progress continues. Ever more stringent EURO standards for new vehicles continues to exert downward pressure on this type of emission. The fact of taking into account in the model links between speed and emissions, as well as the dissemination of technological progress for cars (from COPERT data and prospective studies by Hugrel and Joumard, 2004) lead one to believe that there will be a significant decline in NO_x emissions from transport in the Lyon urban area, in the order of -52 to -56% (according to the diffuse sprawl and multipolar development scenarios respectively), which can be seen in Figure 6.

Increased distances contribute to the increase in CO_2 emissions

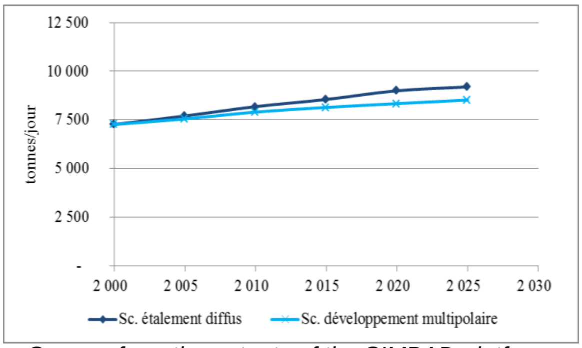
As shown by the two curves in Figure 7, CO_2 emissions related to daily mobility in the Lyon urban area remain on the increase, as the expected energy performance improvement is too small (Hugrel and Joumard, 2004). They increase by 17% in the multipolar development scenario and by 27% in the diffuse sprawl scenario.

Figure 6: Changes in daily emissions of NO_x



Source: from the outputs of the SIMBAD platform

Figure 7: Changes in daily emissions of CO_2



Source: from the outputs of the SIMBAD platform

Costs of everyday household mobility rise, worsening the gap between income groups

The SIMBAD platform unfortunately does not yet have a "Trip Account" module to provide an estimate of the overall cost of the travel subsystem and its distribution between the different people involved (households, companies, local authorities and the State). However, the types of mobility modelled can be used to estimate the cost they represent for those who use them. A review of the changes in costs for different categories of households based on their location and income (Figure 10) can be set against the deterioration of accessibility estimated in the previous section.

In terms of mobility costs, the initial situation already appears highly differentiated according to location: 2.4 times greater for a person living in the 1st ring than for a resident of Lyon and Villeurbanne, and even 4.3 times higher in the 2nd ring. It is difficult here to judge the fairness or otherwise of the situation because at the moment SIMBAD calculates an average price per m2 of housing per area but does not estimate the cost this represents for each household, depending on its size and its income.
However, one can emphasize the heterogeneity of situations between incomes in the case of a location in the same suburban zone, since the income gap is between 1 to 5.4 between the 20% of poorest households and the 20% of wealthiest, while their mobility cost differentials are only 1 to 2.0 in the centre, 1 to 1.8 in the 1st ring and 1 to 1.4 in the 2nd ring. Cost pressure on daily mobility weighs less on the budget of wealthy households than on that of low-income households, and this pressure difference is amplified as one moves away from the centre.

Figure 8: Changes in the cost of daily mobility per person based on income and location - multipolar and diffuse scenarios

Source: from the outputs of the SIMBAD platform

When one then examines the dynamics provided by the SIMBAD simulations, the overall increase in the costs of individual daily mobility is limited to changes in distance, since the unit cost components were set as constants here. It remains in the order of 5% in the multipolar development scenario and 17% in the diffuse sprawl scenario.

However, this average trend hides a very strong asymmetry between a general decline in costs in the centre (39% in the first scenario and 43% in the second) and the 1st ring (-18 and -16% respectively) and a net increase in the 2nd ring (+30 and +39%). In the centre and the 1st ring, costs decrease with decreasing distance, enhanced by a partial modal shift from cars to green modes and public transport. By contrast, in the 2nd ring these distances are longer, increasing the use of the car, and costs increase.

So the difference in the average individual cost, which is at the initial date 1 to 4.3 between the centre and the 2nd ring, increases in extremely marked fashion to reach 9.1 in the multipolar development scenario and 10.4 in the diffuse sprawl scenario. It is clear that in both scenarios, with the changes simulated by the model, a large amount of tension is generated between the centre and the outskirts of the urban area - and we have not even given any consideration here to any particular fuel price increases.

Urban sprawl obviously encourages increased costs, which are more or less kept under control depending on the scenario. It combines with an aging population and a preference for central areas by older households who are very present in the model's logic. The fact that they do not have to travel for work reasons limits the distances and their car use, which further amplifies the differences in average costs between centre and outskirts.

CONCLUSION

How should one present the results of a Land- Use and Transport Interaction model in the context of sustainable mobility? To answer this question, this paper has put forward the example of the SIMBAD model applied to the Lyon urban area. It shows that the wealth of results can be used to develop a fine analysis of the changes in the system. These can be organized according to "sustainable development" logic, with a first level of analysis of interactions between locations and travel then, secondly, weighing the changes in services provided by the travel system against its negative impacts, with each of these cost / benefit terms broken down into the three dimensions of sustainable development.

More specifically, because the initial ambition of SIMBAD, which was to provide a strategic vision for transport and planning policy, too fine a spatial level does not make much sense. The main trends have been well illustrated here by partitioning into 6 zones, with a twin radial-concentric and East/West analysis.

The application of the two scenarios shows that significant contrasts can be detected using these indicators, even in the extremely simplified cases examined here. Combining them provides understanding of the changes captured by the model and at the same time gives a broad and coherent vision of impacts in terms of sustainable mobility. A "trip account" module still remains to be completed to include network operating costs and investments in order to have a complete vision.

Finally, in the longer term, it will also be necessary to go beyond the 'transport' input which was used here to define these sustainable mobility indicators. The current modelling of the real estate market in SIMBAD estimates changes in average price per m2 of housing in each area, but not does not provide any differentiation by type of household. Having a closer relationship between housing type and household type will indeed provide a better account of the balance between housing cost and mobility cost and the remaining disposable income for the household budget.

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