Assessing 50 innovative mobility offers in low-density areas: A French application using a two-step decision-aid method

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Assessing 50 innovative mobility offers in low-density areas: A French application using a two-step decision-aid method

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Abstract: In this article we propose a decision-aid tool for local authorities to plan and implement their transport policies. We set out sustainable-mobility scenarios that depend on the geographical contexts of different areas based on 50 mobility offers, including active modes, car-sharing, public transport, etc. To do so we appeal to a multi-criteria decision analysis (MCDA), relying on an original two-step assessment method. We first use the *diviz* decision-aid tool to obtain a global score for each mobility offer, on the basis of 18 criteria covering the three pillars of sustainable development (economy, environment and society) and the concerns of the mobility actors themselves (historical actors, newcomers, public authorities and users). This step supports mobility management by local authorities, as it makes it possible to rank mobility offers by type of area. Second, we use the *MICMAC* decision-aid tool to construct the influence and dependency relationships between our 18 criteria. The aim of this step is to identify some relevant criteria that are determinant in a prospective or strategic analysis, in order to consider what could be a development scenario for the future of everyday mobility in various areas. As alternatives to personal car are rare, we apply this two-step method to the case of low-density areas, and find highlighting results concerning the role of carpooling combined with walking, both being assisted by a powerful mobility application.

Keywords: Multi-criteria decision analysis, decision-aid, low-density areas, transport policy, *diviz*, *MICMAC*.

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1. Introduction

Mobility is a structural component of our contemporary lifestyles. The transportation of people and goods is a key sector of economic activity and contributes to the urban and social integration of citizens (Urry, 2016). In this context, "automobility" (i.e. car use as the dominant transportation mode) remains a shared feature of individuals who seek autonomy and comfort when travelling, even if it no longer meets the socio-cultural standard of success.

For fifty years, transportation policies were managed in most countries by governments and local authorities around the idea of complementarity between individual and collective mobility. Road development should allow both economic development and the freedom of car owners, while public transport (adapted for most urban users) should limit the total costs and negative externalities associated with private cars. Indeed, automobility is increasingly constrained by a number of costs: economic (increasing transport costs for users), environmental (pollution and the scarcity of resources), social (exclusion) and socio-territorial (the level and distribution of income in the local area, the physical limits of cities in terms of transport flows).

As such, local authorities now need to rethink mobility to guarantee the movement ability of all. The analysis of mobility supply should focus on travel needs in order to facilitate intermodality for mobility users. The current trends in the development of mobility services and public-private partnerships follow this user-centered logic.

Despite encouraging signs, innovative mobility offers still face several psychological and sociological obstacles to behavior change (Brette et al., 2014, Créno, 2016, Dantan et al., 2017). Car-sharing generally represents only low modal shares.[1] While BlaBlaCar is a testament to the success of ride-sharing on long-distance trips in over twenty different countries, there are a number of difficulties with short-distance carpooling. While ride-hailing or private-hire companies like Uber or Lyft seem to respond to strong expectations from mobility users, for the moment they have only appeared in dense areas. A common feature of innovative mobility offers is their reliance on Intelligent Transportation Systems, which “early adopters” use via mobility applications on their smartphone (Dantan et al., 2015, Le Lab Chronos Ouishare, 2017).

[1] See for example the failure of Autolib’ in Paris in 2018.

Public transport also faces a major challenge in the integration of new mobility offers into the map. It must adapt its strategies to maintain significant market shares, particularly in low-density areas where it currently struggles to provide efficient services (Bulteau et al., 2018). As for active modes (cycling, walking, and micromobility objects such as kick scooters), public transport remains strongly dependent on urban planning that is designed to render it attractive to potential users. Moreover, the emergence of the “inclusive mobility” concept may provide mobility for everyone, independent of age, physical capacity, gender or income (Deloitte, 2017). In this context, innovative offers require that the institutional context be considered in decision-making models and integrated into the transport map.

The management of everyday mobility is thus a concrete way to fit the needs of the territory, including social, civic, economic, environmental and cultural life. This article contributes to this view: the development of a decision-aid tool of transport-mode planning for local authorities who are decision-makers, by reducing the environmental and social impacts and preserving a quality of life that is acceptable to residents (Verhoef, 1996, Le Boennec and Sari, 2015, Brécard et al., 2018).[2]

In this context, the increasingly fuzzy boundaries between the nature of vehicles, the specific needs of territories and the new typologies of users faced with mobility offers require us to address the conditions of evolution and determination of "transport ecosystems". Faced with so many factors, there is a need for decision-aid tools to assess innovative mobility offers for given territories and scenarios in order to implement these offers.

To do so, we brought together information on mobility offers (producing raw data and monitoring international best practices), analyzed data on Mobility as a Service offers (MaaS), and assessed offers and their implementation conditions in a given territory. This action research recently led to the establishment of an “observatory of new mobility solutions” financed by the VEDECOM Institute (Le Boennec et al., 2018). This observatory retains different assumptions for the parameters of mobility systems. In this optic, we define a typical user profile for every kind of transport mode, retain a typology of mobility offers, check the composition of the transport ecosystem and characterize a typology of territories. The observatory of new mobility solutions is thus a preferred tool for systematically monitoring new solutions launched on different markets, selecting solutions with particular characteristics in terms of service innovation, assessing them in various geographical contexts, based on a number of available data.

Concerning the *nature of the vehicle*, transport is identified by capacity (from personal to collective),

[2] In particular, air quality is at stake in many French and European cities.

status (personal vehicle, self-service fleet, shuttle operated by a firm) and function (transport of people, goods, hypermobile places). There is a common trend towards greater flexibility by increasing combinations of the above. Moreover, given the cost of current or future public transit in medium to large cities, “the car is tomorrow’s public transport” may become a common policy slogan, either as a complement to or a substitute for public transit.[3]

As far as the *user profile* is concerned, we characterize behaviors regarding mobility offers through a distinction between “personal or shared vehicle” (ownership status) and “individual or shared trips” (type of use). This cross typology is influenced by two trends:

- First, *socio-economic changes*: rising life expectancy, specific mobility needs ("young" retired, disabled, "vulnerable groups"), financial difficulties due to the share of transport costs in budgets, the emerging digital economy and connected objects, new labor organizations, the move towards a service economy, the role of public transport, etc.
- Second, *evolving mobility practices* through choice combinations between vehicle and travel: individual or shared trips, new consumption criteria (freedom, efficiency, time-saving, cross-border transport etc.) and collaborative practices through comodality and teleworking. There is no longer an average traveler or a typical day.

The *recomposition of mobility-solution providers* is also important. The transport ecosystem is evolving rapidly with new actors (digital actors like Google) and the need to rethink business models, partnerships, and innovations (Marçal et al., 2017).

Finally, mobility solutions cannot be implemented in the same way in all areas, given the considerable inequality in the mobility services provided. Urban sprawl, the increased multipolarity of territories (producing a great diversity of trips), strongly radial living areas, and socio-demographic and geographical features are all sources of potential inequality in the provision of mobility services. Our *typology of areas* should facilitate the construction and use of the decision-aid tool (Subsection 2.1).

Every transport policy needs to be assessed due to its costs and irreversible effects on a territory. Implementing policies requires that decision-makers decide between alternative projects on the basis of many considerations (International Transport Forum, 2011): will the project achieve its environmental objectives? Will it cost too much compared to the expected benefits? Does it meet the territory’s needs? We here need to estimate the opportunity cost of mobility offers.

[3] For example, the Fleetme carpooling lines service in medium-sized French cities, or the Chariot on-demand transport service in the US.

To answer these questions, we use multi-criteria decision analysis (MCDA) so that a number of criteria can be considered simultaneously (Munda et al., 1995, Salling and Pryn, 2015, Barbosa et al., 2017). Note that alternative types of analysis, such as Cost-Benefit Analysis (CBA), allow us to take decisions in a context where the impacts of a transport project can be monetized (Quinet, 2010). However, there are many situations for which the monetary value of a criterion cannot easily be attributed: broadly speaking, this refers to the social and environmental dimensions (Joubert et al., 1997, Tudela et al., 2006). As a result, whenever the evaluator does not offer a quantification of an impact (even if it is imprecise), this impact cannot be considered in the assessment. This risks skewing the selection of "good" projects (International Transport Forum, 2011). Last, CBA is mainly used for large infrastructure projects (although not exclusively) and may not suit well for the assessment of local mobility offers like bike-sharing for example (Beria et al 2012).

An MCDA may thus be preferred by the decision maker (Hüging et al., 2014, Bueno et al., 2015). This type of analysis may be appropriate when considering the behavior of users and taking a broader approach than the calculation of social costs (Ramin et al., 2018). A common view is that an MCDA assesses more impacts, responds more directly to the concerns of decision makers, and is open to various weighting strategies applied to the assessment criteria (International Transport Forum, 2011).

We develop an MCDA tool in order to identify the mobility offers that meet the users' main expectations for their daily trips:

- *Simplicity* and the guarantee of psychological comfort;
- *Transparency* of information so that the experience feedback is maximized;
- *Instant service* through real-time information; and
- *Door-to-door* travel in route calculations.

These expectations define the scope of the mobility offers under consideration here. More precisely, we in this article seek to assess the existing or emerging mobility offers that could induce autosolists (single-occupancy car drivers) to adopt sustainable mobility offers: public transport, active modes and shared mobility (carpooling, car-sharing, shared taxi or private-hire). We try to understand the features of exclusive autosolists.

The objectives of this article are first to rank, among 50 selected items, the mobility offers for local authorities. This first step helps to identify the strengths and weaknesses of single mobility offers in a specific type of territory. We use the *diviz* decision-aid tool (Meyer and Bigaret, 2012; Bigaret and Meyer, 2015) to obtain a global score for each offer, using 18 *ad hoc* criteria that cover the three pillars of sustainable development: economy, environment and society (see Faucheux and Nicolaï, 2004a, for the criteria-building method).

In the second step, we use the *MICMAC* decision-aid tool to construct relationships of influence and dependency between the criteria (Godet, 2000, Godet and Durance, 2011). We identify for each type of territory the variables that play a dominant role in the transport ecosystem, in order to propose different spatial-planning scenarios.

The remainder of the paper is organized as follows. Section 2 describes the methods we used to collect and analyze data for the two-step decision-aid tool for local authorities. Section 3 presents the implementation of the two-step method. Section 4 discusses our results, setting out the spatial-mobility scenarios. Last, the concluding remarks appear in Section 5.

2. Material and methods

Our original two-step method has two complementary goals: supporting spatial and temporal transport policies, as the management and the strategic parts of them.

2.1. A spatial decision-aid tool for the management of everyday mobility

The first goal of the method is *to identify performing mobility offers* for local authorities in various areas through an assessment process (*using a spatial scale*). Each offer is assessed regarding its socio-economic characteristics. We decide to consider French conurbations as:

- They constitute homogenous territorial units, as local authorities are responsible for transport policy over the entire area;
- They have a variety of population densities and mobility needs; and
- Demographic dynamics inside and/or around conurbations may produce acute mobility problems, especially in the context of a durable scarcity of public funds.

The relevance of a typology of areas regarding our research issue was discussed and agreed on by five territorial experts. We met with three mobility managers from two French medium-sized local authorities (the Versailles conurbation and the Saint-Quentin-en-Yvelines conurbation), and two geography researchers (University of Vincennes-Saint-Denis and the VEDECOM Institute) to construct the typology of territories. These experts were sent an initial typology proposition by the authors, which was then discussed and validated through individual semi-structured interviews conducted by one of the co-authors (see the expert list and qualifications in Appendix A).

Four types of areas are considered with respect to three variables: housing density, employment density, and the commuting flows between housing and employment. This typology is a simplified pattern of the administrative boundaries set up by the French National Institute of Economics and Statistics (INSEE).

(1) Central cities (high-density areas). The deployment of innovative mobility offers (bike-sharing, car-sharing and private-hire) always starts in central cities, as the highest density level is a lever for providers to meet customers in a short time;

(2) Suburbs (dense areas). This is both the physical limit of the city as a whole, and the administrative boundary of the urban local authority. The priority challenge of transport policies in the suburbs is to ensure that the public transport networks allow competitive trips towards the central city, compared with private cars.

The addition of 'central cities' and 'suburbs' constitutes conurbations in our typology.

(3) Central towns in periurban areas (mid-density areas). A number of small or medium towns located in areas around conurbations are served by at least one major transport network intended to facilitate radial accessibility towards the conurbation (mostly railways). The other components of the mobility system (cars, buses, active modes) are organized to promote intermodality and transporting users to the train station of the town;

(4) Other municipalities in periurban areas (low-density areas). In these areas, that are still strongly linked to the conurbations (for example, in France at least 40% of workers in these outermost areas work either in the central city or in its suburbs), there is a lack of mobility governance.[4] They may benefit from services that are managed by larger mobility authorities[5] and be the subject of local experiments. However, the implementation of structured transport policies remains problematic at this level.

2.2. A temporal decision-aid tool for a strategic analysis of local mobility

The second goal of the method is *to set out contextualized mobility scenarios* through a prospective exercise (*as a temporal or strategic perspective*). The two steps of this method therefore require the use of a number of relevant criteria and measurement indicators, while certain results of the

[4] The French Mobility Law, discussed in 2019, is to enhance such areas to become mobility authorities.

[5] The *Départements* and *Régions* in France

assessment process (step 1) are reinjected into the scenario writing (step 2). The complete research process is described in Figure 1.

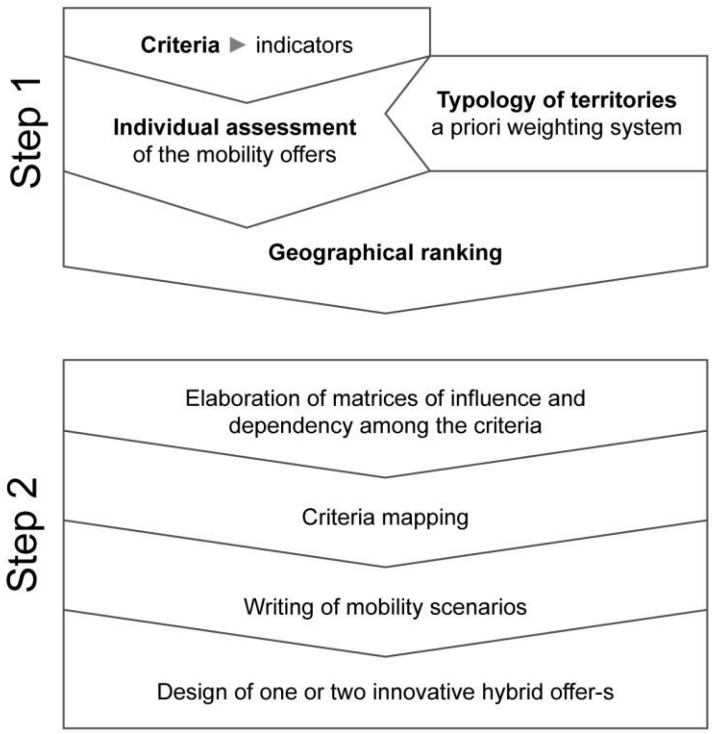

Figure 1. The two-step decision-aid method ***(Source: Authors)***

The indicators in the "observatory of new mobility solutions" by the VEDECOM Institute respect the main characteristics of socio-economic dashboards (Le Boennec et al., 2018), and fulfil the requirements of any indicator (Faucheux and Nicolaï, 2004*b*):

- *Measurable*: quantifiable (or qualifiable) using available tools and methods (with verifiable data);
- *Robust*: measurable constantly over time and identically by observers in different areas;
- *Relevant*: for a given type of area, data is available regarding the objective;
- *Understandable*: there is a clear and shared definition of the indicator from an operational point of view; and
- *Sensitive*: information is added to decision-making.

We opted for an 18-indicator scorecard yielding a comprehensible and adaptable view of the area analyzed (Table 1): six criteria are related to economic issues (both demand and supply, group A), six to environment and health (group B), and six to social and societal issues (incentives for use and the effectiveness of use, group C).

Table 1. List of criteria and measurement indicators for the assessment process

A. ECONOMY						
	Demand factors			*Supply factors*		
Criterion	**A1. Viability of the territory necessary to the implementation of the mobility offer**	**A2. Cost of the mobility offer for the user**	**A3. Time savings allowed by the offer for the user**	**A4. Potential actors ready to get involved in the territory**	**A5. Interoperability of the offer with the existing mobility system**	**A6. Share of public funding in the mobility offer**
Indicator	Socioeconomic dimension of the territory: median income, level of inequalities	Cost of the offer compared to the cost of a personal single-occupant thermal car	Average differential time compared to personal car, including potential breaking bulks	Number of actors ready to get involved in the area for the marketing of the mobility offer	Level of fare integration of the mobility offer with the existing offers	Share of public funding in the costs of the business model of the mobility offer
B. ENVIRONMENT AND HEALTH						
	Energy - Global warming and air pollution			*Other sanitary criteria*		
Criterion	**B1. GHG emission abatement**	**B2. Reduction of energy dependency**	**B3. Improvement of air quality**	**B4. Reduction of noise exposure**	**B5. Improvement of road safety**	**B6. Health benefits associated to the use of active modes (isolated use or intermodality)**
Indicator	Variation per traveler.km of GHG emitted by the offer, compared to personal single-occupant thermal car	Variation per traveler.km of fossil fuels consumed by the offer, compared to personal single-occupant thermal car	Variation per traveler.km of fine particles and nitrogen oxides emitted by the offer, compared to personal single-occupant thermal car	Variation of the mean noise level emitted by the offer at a given point, compared to personal single-occupant thermal car	Variation per km travelled of the number of fatalities and injuries in circulation accidents compared to personal single-occupant thermal car	Reduction of body mass index or cardio-vascular accidents or morbidity index, compared to personal single-occupant thermal car
C. SOCIETY						
	Incentives for use			*Effective use*		
Criterion	**C1. Conditions for territorial development of the mobility offer**	**C2. Personal levers and impediments for the use of the offer**	**C3. Collective levers and impediments for the use of the offer**	**C4. Accessibility of the offer for vulnerable users: elderly, disabled**	**C5. Frequency of use of the offer**	**C6. Satisfaction provided by the use of the offer**
Indicator	Modality of co-construction of the offer with local conditions: safety, planning, infrastructure	Personal motive or combination of personal motives favorable to the use of the offer: convenient and comfortable, affordable, inspiring confidence	Share of collective motivations favorable to the use of the offer: social relationships, solidarity, environmental	Share of use or intent of use of the offer by vulnerable users	Share of users who used the offer at least once the year preceding the survey	Satisfaction index concerning the mobility offer

To ensure the robustness of our proposal, the criteria and measurement indicators were presented for validation to an expert group in mobility issues (see Appendix A). We opted for a procedural logic of expertise based on the importance of the discussion in the decision-making process inspired by Habermas (1991) and we mobilized experts from different horizons in order to ensure transparency in the elaboration of scenarios and in the enlightened management of unavoidable conflicts of interest. Nine qualified individuals were invited to discuss the best criteria and indicators during a workshop. Eight of these were external to the VEDECOM Institute. Six were researchers, with the remaining three coming from civil society (the industry or tertiary sectors). We proposed that they discuss then validate a subset of six criteria and indicators referring to one of the three pillars of sustainable development through three parallel focus groups (group A, B or C).

3. Calculation

3.1. The first step of the method, using *diviz*

The *first step* of the method compares the various mobility offers in order to establish a ranking for local authorities so that they can choose, as mobility managers, the most suitable one(s) for their territory. Each mobility offer was compared to single-occupancy car use, as the reference offer. We used a variety of sources that helped us to draw an initial proposition of criteria and indicators for the experts, then carry out the assessment: institutional reports, surveys, generalist and specialized media, the website of the mobility offer, and academic articles (see the detailed sources that were used in Appendix B).

To process the assessment, we used the *diviz* software, as it is "*a software for modeling, processing and sharing MCDA techniques and experiments*" (Meyer and Bigaret, 2012). The Decision Deck project (which partly lies behind the *diviz* software), was initially aimed to enable the comparison of different analysis methods. *Diviz* has a number of benefits for the practitioner (Bigaret and Meyer, 2015):

- Comparing different MCDA techniques using *a unique interface*;
- Heterogeneous *data inputs* can be integrated;
- *Intuitive* user interface; and
- *Open source*.

The *diviz* software performs the complex computations required by MCDA analyses through a simple design and the rapid execution of successive sequences of calculation as a workflow (Fig. 2) (Cailloux et al., 2013).

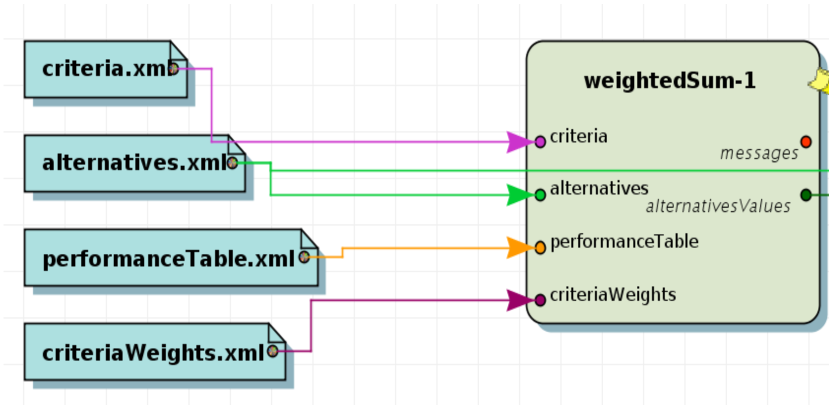

Figure 2. A typical *diviz* workflow *(Source: Meyer and Bigaret, 2012)*

Before processing the assessment, a typology of mobility offers was established. We retained the most representative offer(s) in each category, namely (Appendix C):

- First, the offer that regionally attracts the largest number of users (e.g. BlaBlaCar for carpooling, Uber for private-hire, and Google Maps for the multimodal information app);
- Second, if relevant, an offer that is differentiated from the leader, so that potential users in areas where the offer has not yet been launched could benefit from a service innovation (Oui'Hop for carpooling, G7 taxis using a reservation app in Paris, or the Finnish project "tuup" for multimodal information).

50 mobility offers were then prepared for assessment. We calculated the WeightedSum component of *diviz* (Meyer and Bigaret, 2012) in order to produce a weighted sum of alternatives with respect to a territorial-weighting strategy. Criteria weights were applied for the four types of territories presented in Subsection 2.1: (1) high-density, (2) dense, (3) mid-density and (4) low-density. We attributed six weights to the four territories, corresponding to the six subgroups of three criteria that were validated in Table 1:

- *Group A ('Economy')*: demand (A1, A2, A3) and supply factors (A4, A5, A6);
- *Group B* (**'***Environment and health')*: Global warming and air pollution (B1, B2, B3), other health criteria (B4, B5, B6);
- *Group C ('Society')*: incentives for use (C1, C2, C3) and effective use (C4, C5, C6).

The performance table as another input for *diviz* is thus the crossing of the results of the assessment of these 50 alternatives with the 6 subgroups of criteria; in a first stage, this assessment is carried out independently of the type of territory. The WeightedSum aggregation operator of *diviz* then applies the criteria weights to the performance table in order to obtain the weighted results of the 50 alternatives for the four types of territories (Fig. 2).

3.2. The second step of the method, using *MICMAC*

The second step produces the contextualized mobility scenarios as a strategic analysis. We here use *MICMAC* software (Godet, 2000, Godet and Durance, 2011, Shoai Tehrani and Da Costa, 2016) which applies a structural-analysis method to produce a graph of direct influences and dependencies (Fig. 3). We here attempt to construct relationships of influence and dependency between our predefined variables, namely the 18 criteria that were validated in the first step of the method. These relationships serve to establish the mobility scenarios.

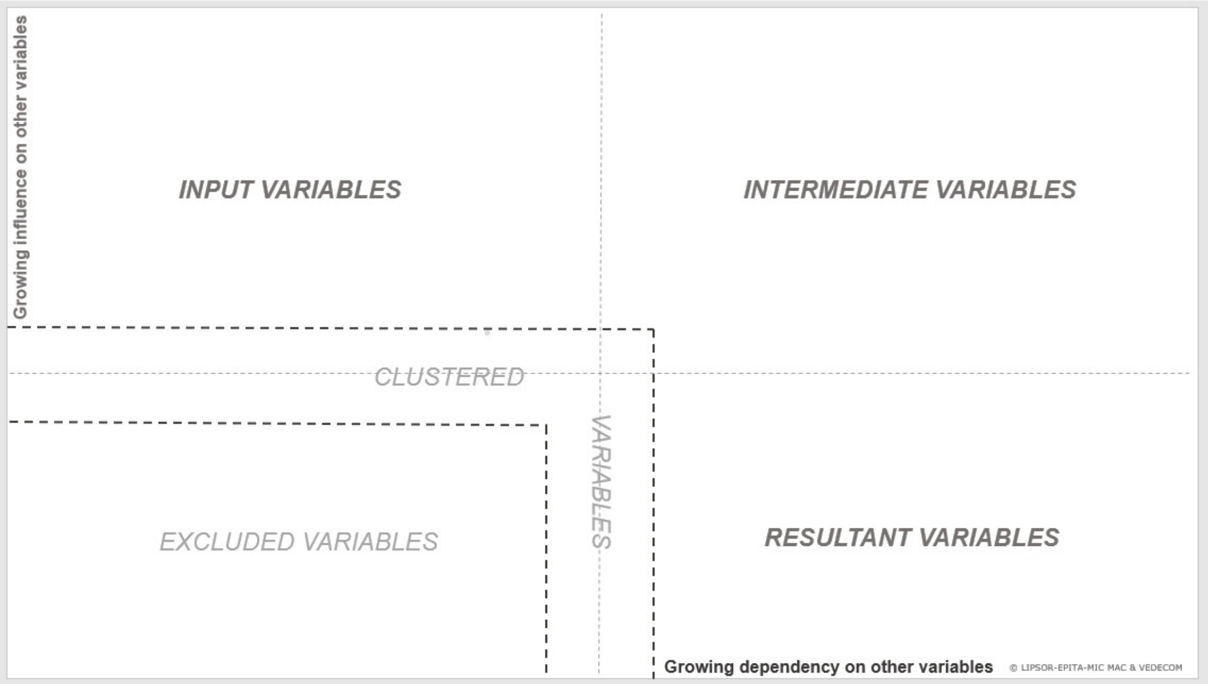

Figure 3. Graph of direct influences and dependencies: general case *(Source: Shoai Tehrani and Da Costa, 2016)*

A mapping of the influential and dependent variables is proposed as in Figure 3, which shows the general meaning of the variables according to their position in the graph (Shoai Tehrani and Da Costa, 2016):

- Northwest part of the graph: exogenous or *input* variables, as they prove to be highly influential still not highly dependent on the other variables;
- Southeast: output or *resultant* variables, for the opposite reasons. Their behavior describes impacts from input and intermediate variables;
- Northeast: *intermediate variables*, i.e. variables with interactions, given the fact they are both highly influential AND dependent;
- Southwest: *clustered* (central part) and *excluded* variables. There is no clear interpretation of these variables ('clustered'), or they describe inertial trends that change little over time ('excluded').

How is this graph obtained? For different types of territories, a matrix of relationships between all the criteria taken in pairs, called Matrix of Direct Influences (MDI), is first filled (section 4). The rating system ranges from "(0) no influence/dependency of variable 1 on variable 2 " to "(3) very strong influence/dependency of variable 1 on variable 2 ". Filling the MDI consists in identifying the cross-influences between the variables of our list.

To describe the process accurately, we specify that two of the co-authors were responsible for filling out the MDI according to the type of territory. To process the fulfillment, they relied on two types of inputs: first, the results of the discussion of the 18 criteria from the mobility expert group (nine experts), that led to a shared definition; second, the sensitivity of different types of territories to those criteria, leading to specific weighting strategies that were discussed and validated by the territorial experts (five experts). As this would have been unrealistic to ask to 14 experts to fill out each of the boxes of the matrix, the co-authors processed it themselves: they first carried out this exercise separately and then compared and discussed their results one by one, finally producing one MDI per territory type with a single score for each pair of variables. Finally, this concatenation work of the co-authors was the subject of a feedback to the experts consulted for discussion and validation in March 2018.

An example of an MDI appears in Table 2: here variable (A1) *'Viability of the territory'* has maximum influence on variable (C5) *'Frequency of use of the offer'*. On the contrary, (B3) *'Air quality'* has no effect on (A3) *'Time savings allowed by the offer'*. We do not assume that the variables depend only on the other listed variables. For example, the *'Cost of the mobility offer for the user'* (C2) is not modelled as a function of individual income, which could affect the user's decision to choose an alternative solution to his/her personal car to make his/her trip.

Table 2. Example of a Matrix of Direct Influences (MDI)

	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5	B6	C1	C2	C3	C4	C5	C6
1 : A1_VIAB		0	0	1	0	3	2	2	2	2	1	1	2	3	3	2	3	2
2 : A2_COST	0		0	3	3	3	3	3	3	3	1	1	2	3	2	0	3	3
3 : A3_TIME	0	3		0	3	2	0	0	0	0	0	0	0	3	2	1	3	2
4 : A4_ACT	0	3	3		3	3	3	2	2	1	1	1	3	2	1	1	2	2
5 : A5_INTER	0	3	3	3		3	1	1	1	1	1	1	2	3	2	1	3	2
6 : A6_FUND	0	3	0	3	3		3	2	3	1	1	1	3	3	2	3	3	2
7 : B1_GHG	0	3	0	3	3	3		3	2	0	0	2	0	0	3	0	0	1
8 : B2_DEPEN	0	3	0	0	0	1	3		1	0	0	2	0	0	2	0	1	1
9 : B3_AIR	0	1	0	0	0	1	1	0		0	0	1	0	0	2	0	1	1
10 : B4_NOISE	0	0	0	0	0	1	0	0	0		0	1	0	0	2	0	0	0
11 : B5_SAFE	0	0	0	0	0	1	0	0	0	0		1	1	1	2	3	1	1
12 : B6_HEALTH	0	0	2	0	2	1	3	3	2	1	2		1	1	1	0	3	3
13 : C1_DEV	0	3	2	3	3	3	3	3	2	2	1	3		3	3	3	2	2
14 : C2_PERSO	0	0	0	3	2	1	0	0	0	0	0	0	3		2	2	3	2
15 : C3_COLL	0	0	0	3	2	2	0	0	0	0	0	0	3	0		2	1	1
16 : C4_VULN	0	0	0	1	2	3	0	0	0	0	0	0	3	0	3		3	2
17 : C5_FREQ	0	2	0	2	2	3	3	3	3	3	1	0	3	3	2	3		3
18 : C6_SATIS	0	0	0	3	2	3	0	0	0	0	0	0	3	3	2	0	3	

Note: This matrix reveals the degree of influence of the row variable on the column variable.

Using the MDI, the *MICMAC* software generates the graph of the direct influences and dependencies (Fig. 3). Afterwards, contextualized mobility scenarios can be written using the influential and dependent variables, adding some striking results of the assessment process in the first step for relevant mobility offers in certain areas (See Subsection 4.3).

4. Results

4.1. Step 1: the results after *diviz* processing

The results obtained from the *diviz* WeightedSum process are described in Figure ~~3~~4. The Y-axis corresponds to the scores of the assessed mobility offers, resulting from the territorial-weighting process, while the X-axis indicates the type of area for which the offer is assessed, from (1) *'Central cities'* (high-density) to (4) *'Other municipalities in periurban areas'* (low-density).

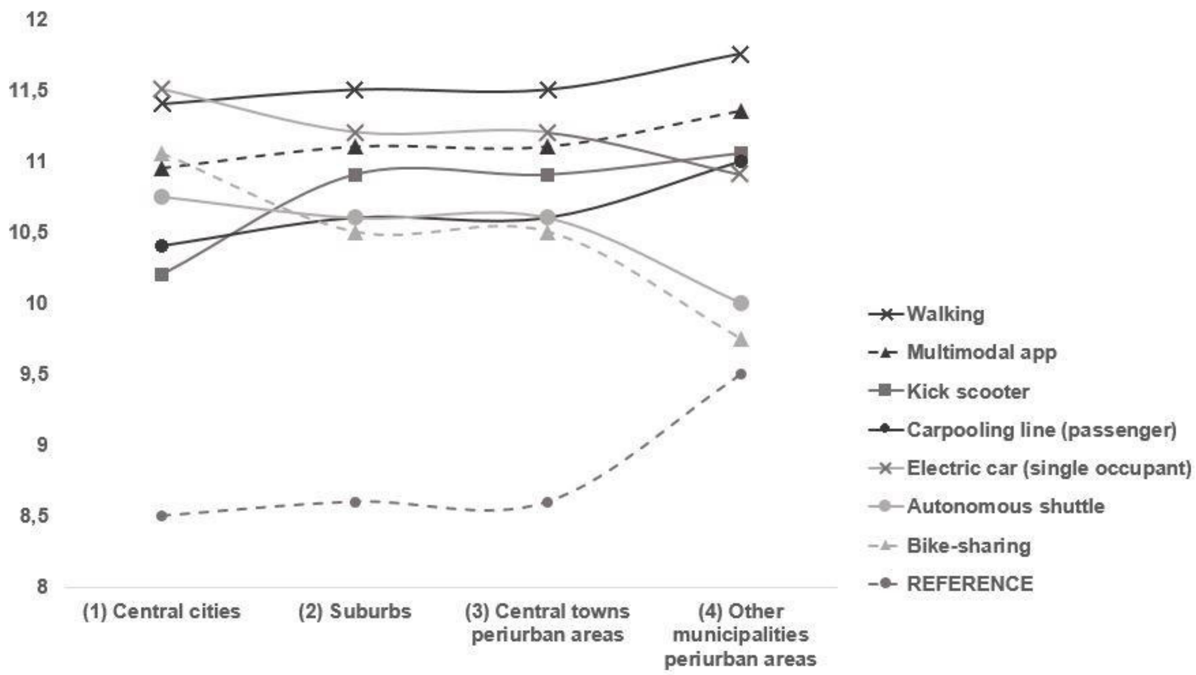

Figure 4. Compared spatial performances of the seven best-ranked mobility offers plus the reference offer (step 1, *diviz*)

Note: For each offer in each type of area, the score for the Y-axis is obtained by multiplying the result of the assessment for each subgroup of three indicators by the weight coefficient applied to this subgroup.

We retain the seven best-ranked mobility offers, before territorial weighting: these cover three active modes (walking, kick scooter and bike-sharing), two electric modes (one of them, the autonomous shuttle, being experiential in Lyon, France), and an original carpooling line offer analyzed from the passenger viewpoint (the Fleetme offer in three medium-sized French conurbations). A multimodal application (the "tuup" experiment in Finland, afterwards launched as Whim) is added as the most efficient mobility assistant.

In each type of area, we compare the outcomes from these alternatives to the reference offer (a single-occupant car with thermal power). Figure 5 additionally provides the performance details in each of the six subgroups of criteria in Table 1: to preserve readability, only the four best-ranked mobility offers are considered, plus the reference offer.

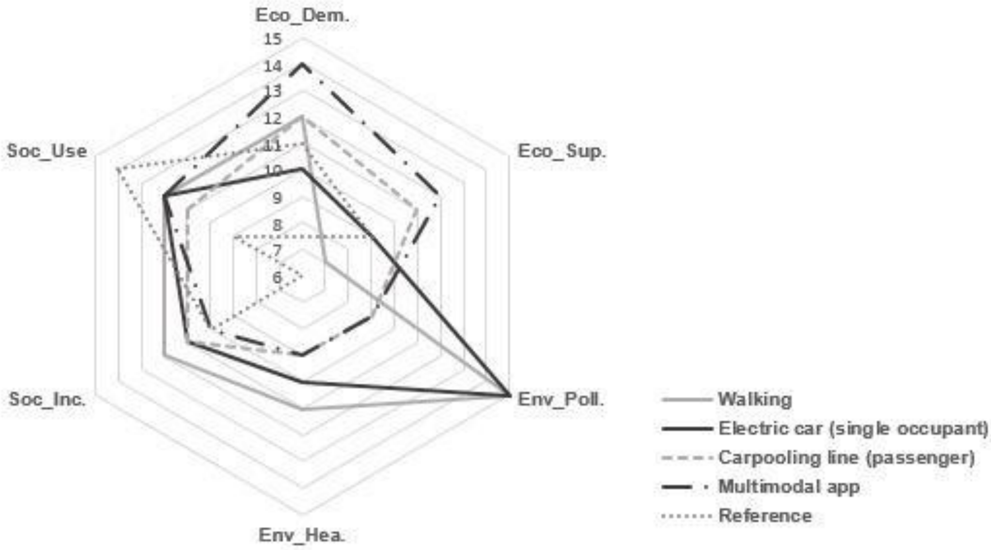

Figure 5. Detailed performances of the four best-ranked mobility offers, plus the reference offer (step 1)

Reference offer: In (1+2) high-density and dense areas (central cities and suburbs), but also in (3) mid-density areas (central towns in periurban areas), the thermal single-occupant car produces poor results (Fig. 4). This is due to its low environmental scores (GHG emissions, air quality, noise, safety and health benefits, see Env_Poll. and Env_Hea. in Fig. 5). On the contrary, in (4) low-density areas (other municipalities in periurban areas) the economic demand factors are considerable (saved travel times, and cars deployed everywhere independently of local income and inequalities, see Eco_Dem. in Fig. 5), producing a higher score. Another explanation lies in the fact that the modal shares and satisfaction of single-occupant car jointly rise as population density falls (Soc_Use, Fig. 5).

Active modes: Surprisingly, walking is the mobility practice with the highest score, except in central cities (Fig. 4).[6] The high walking score reflects economic factors (walking is costless for users, see Eco_Dem. in Fig. 5), global environmental performance with the exception of road safety (Env_Poll. and Env_Hea.), and social and societal benefits (a universal mobility offer, convenient and inspiring confidence: Soc_Use and Soc_Inc.). The increase in performance as population density falls (Fig. 4) is especially due to the higher weights on demand factors (Env_Dem.) and incentives to use (Soc_Inc.). The pattern for kick scooter as the second-best active mode is comparable (Fig. 4), but with lower scores for all criteria (less effective use, and fewer individual and collective incentives). The spatial pattern for the last active mode, Vélib' (the Paris bike-sharing offer) is opposite (Fig. 4), as the demand factors receive only moderate scores: the offer is only available in rich high-density areas.

[6] The electric car is the best-performing offer in central cities, but the small performance difference between those two offers does not allow for a clear ranking.

Electric modes: The results for electric modes have certain common features with the active modes regarding environmental factors.[7] For the moment, travel times using autonomous shuttles are still not competitive compared to private cars in low-density areas (demand factor). This explains its poor result in this type of area (Fig. 4). In a comparable way, electric cars have lower scores in low-density areas because of lower weights regarding environmental factors (Env_Poll. in Fig. 5). The scores for the five remaining criteria subgroups are homogeneous, with the exception of economic supply factors (costly investments in electric charging stations for local authorities, Eco_Sup.).

Carpooling: because of the general benefits of car use (with the exception of time savings), carpooling follows the same spatial pattern as single-occupancy (Fig. 4); however, because the negative environmental externalities are divided by the number of passengers carried, the carpooling scores in each type of area are far higher than those for the single-occupant car (Env_Poll. In Fig. 5).

Mobility assistant: Last, the mobility assistant ("tuup") obtains high scores in every type of area (Fig. 4). This comes from economic demand factors (no geographical variation in implementation, costless for users, and potential time savings, see Eco_Dem. in Fig. 5), supply factors (costless for local authorities, a significant lever for the interoperability of various mobility offers, Eco_Sup.) and effective use and high user satisfaction (Soc_Use).

4.2. Step 2: the results after MICMAC processing

The *diviz* scores emphasize the strengths and weaknesses of the individual mobility offers. However, it is not sufficient to write contextualized mobility scenarios. We now consider more general drivers by territory type. The originality of our approach is to take the 18 initial criteria and consider potential relationships of influence among them depending on the type of area, through *MICMAC* processing.[8]

We apply the method described in Subsection 3.2. We retain for the *MICMAC* processing and for the rest of the article the low-density type of areas (4), *'Other municipalities in periurban areas'*), due to the lack of alternatives to private cars there. We believe that mobility challenges are more acute in such areas compared with dense areas, giving the lack of, first, mobility providers (because of low profitability prospects) and second, a local governance able to manage them (but the Mobility Law is about to reform the institutional organization in periurban areas in France).

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[7] We consider here a single trip, not the complete environmental impact of the mode via a Life-Cycle Assessment. It is not the transport mode itself, rather its use which is being assessed here.

[8] Note that this stage of scenario construction will only be addressed in methodological form here, as viable development scenarios in a given territory will depend on analyses and data that are specific to the local context.

The corresponding mapping of the MDI for the 18 variables appears in Figure 6 as an application of the general case in Figure 3 for a low-density territory.

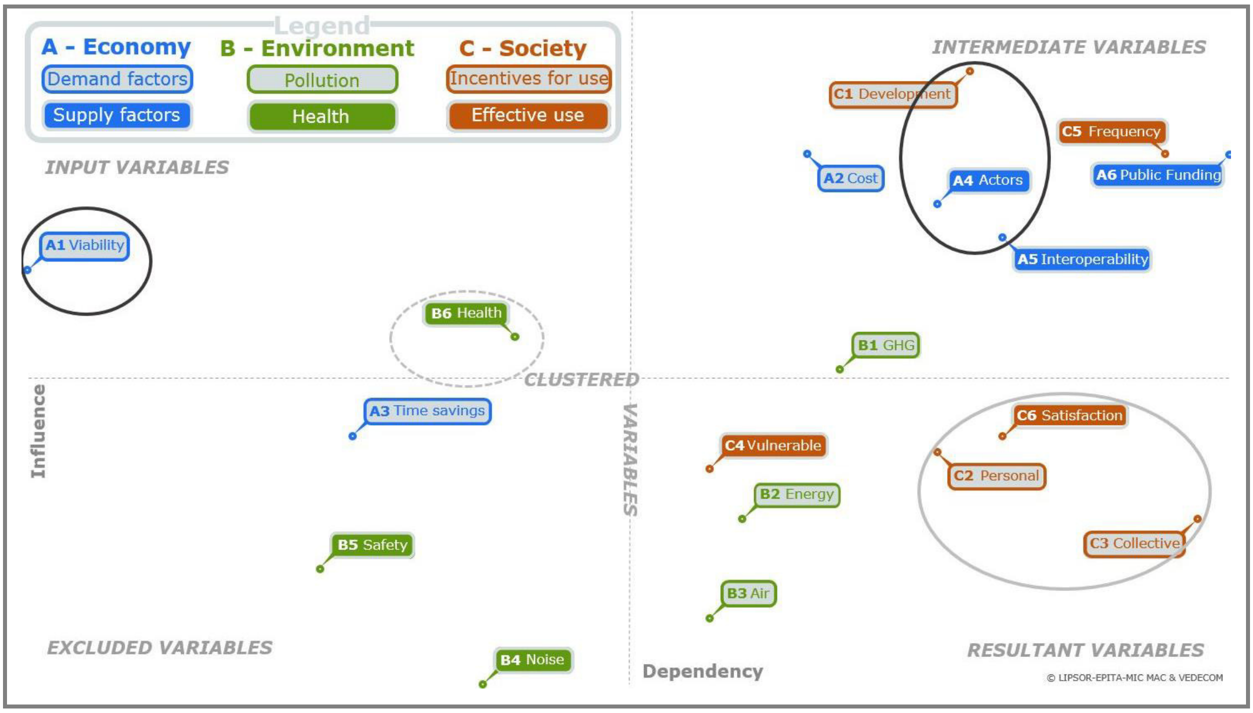

Figure 6. Graph of direct influences and dependencies between criteria for a low-density territory (Step 2, *MICMAC*)

The Y-axis shows the growing influence of the variables: influential variables are for example (A1) as an 'input variable' regarding the typology in Figure 3 (only influential, not dependent), and (A5), (A4) and (C1) as 'intermediate variables' (both influential and dependent). The X-axis shows the degree to which variables are influenced by others: for example (C2), (C6) and (C3) are 'resultant variables' (highly dependent, little influential). The variables close to the center of the graph ('clustered variables', see Fig. 3) are neither significantly influential nor dependent on others: (B6) here.

4.3. Combining steps 1 and 2: writing a virtuous mobility scenario in low-density areas

Following Shoai Tehrani and Da Costa (2016), we develop below forward-looking scenarios based only on the criteria that are influential, i.e. located in the top half of the graph. Table 3 shows the eight scenarios (S_1 to S_8) that may exist in the future in low-density areas: these are function of the higher or lower level of drivers that were constructed only from the influential criteria. The drivers merge the selected influential criteria and constitute the '*influential variable indices*' in the first and second columns in Table 3. Given the possible feedback effects between variables in the North-Eastern quadrant of Fig. 6, high-high (S_1 and S_2), high-low (S_3 to S_6) and low-low mobility scenarios (S_7 and S_8) may occur (fourth column).

Table 3. Eight mobility scenarios for low-density areas

Influential variable index 1: Viability of the territory	Influential variable index 2: Maturity of the ecosystem	Attitude/ Modal shift	Scenario
High	High	+	S_1
		-	S_2
	Low	+	S_3
		-	S_4
Low	High	+	S_5
		-	S_6
	Low	+	S_7
		-	S_8

In addition, in order to consider the results of the *diviz* process, we also retain the high-scoring mobility offers and use them to construct mobility scenarios (See Subsection 4.1). Carpooling, active modes and multimodal applications are thus reinjected into the scenario writing of low-density areas. Those variables are approximated by the attitude of users towards alternatives to single-occupant cars, which may be more or less favorable (the third column of Table 3).

In low-density areas, the two strongly drivers are (1) the viability of the territory (A1), capturing the levels of income and inequality (mean income, and the variability of mean income), and (2) the maturity of the ecosystem (Table 3). The latter is an aggregation of three individual criteria of the economic and social groups: *'Potential actors ready to get involved in the territory'* (A4), the *'Interoperability of the mobility offer with the existing system'* (A5), and the *'Local conditions for the development of the offer'* (C1). These three criteria combined into an influential variable index are in the North-Eastern quadrant of the graph (Fig. 6), so that they are not only influential but also dependent (intermediate variables), and as such the ecosystem can exhibit either virtuous- or vicious-circle behavior. Those alternative behaviors are also supported by the positive or negative attitude of mobility users towards modal shift.

Reviewing the methodological issues for the writing of mobility scenarios, the remaining question is how a given territory will evolve according to these drivers. Answering this requires case studies, given the particularities of each territory. We then continue to explore in a general way what the future of mobility could be in low-density areas.

To write a favorable mobility scenario we refer in Table 3 to S_1: according to our method, a virtuous circle would require three drivers:

- Homogeneity in mean income in the territory, suggesting low inequality (A1+),[9]
- A mature transport ecosystem (A4+, A5+, C1+ for a learning ecosystem),
- A positive attitude of users towards modal shift.

As A1 is only influential, not dependent, the territory under consideration does not need to be initially rich to produce virtuous feedback effects. Only homogeneity matters. Such possible moderate level of the mean income in the territory requires that the mobility system is affordable for users (A2+, Fig. 6).

In this virtuous scenario, there initially exists a transport ecosystem. The current actors are ready to cooperate (A4+), taking advantage of favorable conditions enabled by voluntarist local authorities (C1+). These conditions encourage interoperability (A5+) between two or more existing offers. The ecosystem also benefits from potential demand through positive attitudes to alternatives to single-car occupancy (C5+). Improved carpooling at a reasonable cost for users (A2+), facilitated by efficient mobility applications (A5+), becomes more attractive for larger groups of users.

Public finances are initially healthy (A6+), so that territorial management or direct subsidies reinforce the ecosystem, producing potentially sufficient spillovers that the net public-finance cost is only small. Most environmental variables are only dependent (B2-, B3-, B4-, B5-) or insignificant ($B6^0$). According to our method, the incentives to carpool in low-density areas are clearly economic, not ecological.

5. Conclusions

In this article, we have assessed various mobility offers in order to assist local authorities in promoting alternatives to single-occupancy car use for daily trips, through the construction of a decision-aid tool that depends on given territorial features. We rely on an MCDA framework using an original two-step decision-aid tool that first assesses mobility offers as a weighted sum, representative of existing categories (carpooling, car-sharing, private hire, active modes etc.), and then establishes relationships of influence and dependency between the 18 criteria used in the first step. Last, a virtuous mobility scenario can be imagined for various types of areas. We decide to focus on low-density areas, where mobility issues are key. As the two-step method is open to every type of areas, the second step

[9] For example, so that all households in the area may be equally sensitive to the financial incentives to carpool.

(*MICMAC* processing) could thus be applied for high-dense territories, as it was done in the first step (*diviz* processing).

Our first-step (*diviz*) results confirm that thermal single-occupancy car is far more attractive in low-density areas (given its practical aspects) than in dense and high-density areas (given the negative externalities). In addition, carpooling and, more surprisingly, walking perform well in low-density areas. These could be better combined through efficient multimodal information applications, which perform well everywhere. On the supply side, mobility providers act together to improve the quality of service for mobility users, under the condition of there being supportive local authorities who are able to manage an ecosystem. This service quality surprisingly does not include environmental issues in the eyes of mobility users, as the second step of the method (*MICMAC*) reveals that these variables are most of the time dependent or insignificant.

Our most original result is that walking should be promoted everywhere. For example, the city of Montréal adopted the Charter of the Pedestrian in 2006 that follows certain rules for facilities: guaranteeing short travel times, comfort and security, ensuring easy access to commercial areas, and safe walking. What is new here is that these policies should also be applied in low-density areas. Public policies should also encourage carpooling to help car-drivers take passengers frequently. However, it is important that these policies avoid the well-known rebound effects of induced mobility; moreover, carpooling operators tend to target public-transport users as potential passengers, rather than convince car drivers themselves to carpool.

Our two-step process is original. Even our first step is not directly comparable to existing work. For example, the French agency for environment (ADEME) frequently assesses mobility categories (carpooling, car-sharing, active modes and private hire), but does not compare them in a way that enables trade-offs for public policy. Mobility labs such as “La Fabrique des Mobilités” or “Le Lab OuiShare x Chronos” in France are more think-tanks or incubators for mobility start-ups. They facilitate operational professional relationships between newcomers and public authorities, but their role does not go beyond. Our work here is complementary in decision-aid support, in that we propose a quantitative assessment of mobility via an academic method.

This method is open to discussion. We used recent published work as inputs to the assessment process, and there is not so much of this. However, as these largely come from institutional sources (statistical offices, national environmental agencies) and a few consulting companies (6-T, Boston Consulting Group, Chronos), it may be thought unlikely that different evaluators would reach, at this stage, very different conclusions. In our proposal however, we are aware of the need to address the robustness of our results, by going beyond our 4-item typology of territories. We are preparing to start a new stage with local authority managers: a sensitivity analysis will be conducted in order to estimate the contribution of each input parameter (the criteria) to the output variability of a local model (applied scenarios). As a second limit of our approach, we need to qualify what is meant by ‘maturity of the ecosystem’ or ‘positive attitudes towards modal shift’. A user experience analysis could help us.

Local data will enable the transformation of a mobility scenario into an innovative offer. This offer is expected to combine the best components of the individual offers assessed in the first step, considering the drivers emphasized in the second step. A proof of concept will consider the reactions of potential mobility users, the objective being to launch the offer by attaching it to a durable business model. In a low-density territory, the concept is based on the development of infrastructures dedicated to active modes (walking, cycling and micromobility objects). In a small town not served by mass transit (under 10,000 inhabitants), these infrastructures are expected to tackle the need for households to own a second car. Specific lanes will allow individuals or families to reach carpooling stations from the center to the boundaries of the town, experiencing convenient, safe and pleasant trips. Parking facilities for cycles and kick scooters will be proposed in the stations. The analysis of the results of this proof of concept is left for future research.

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Appendices

Appendix A: List of the experts consulted for the assessment process (Source: Authors)

Expert	Field of expertise	Applied to	Affiliation	Position	Data collection
#1	Public policies	Typology of areas	Saint-Quentin-en-Yvelines conurbation	Director of mobility	Interview
#2	Public policies	Typology of areas	Versailles Grand Parc conurbation	Transport project manager	Interview
#3	Public policies	Typology of areas	Versailles Grand Parc conurbation	Head of innovative mobility offers	Interview
#4	Geography	Typology of areas	University of Vincennes Saint-Denis	Associate professor	Interview
#5	Geography	Typology of areas	VEDECOM Institute	Research analyst	Interview
#6	Economy	Mobility issues	University of Versailles-Saint-Quentin-en-Yvelines	Associate professor	Focus group
#7	Economy	Mobility issues	University of Paris Sud	Full professor	Focus group
#8	Economy	Mobility issues	Xerfi	Head of applied economics	Focus group
#9	Environment	Mobility issues	SystemX Institute	Associate professor	Focus group
#10	Environment	Mobility issues	Laboratory of Accidentology, Biomechanics and human behavior (PSA-Renault)	Director	Focus group
#11	Environment	Mobility issues	French Institute of Petroleum and New Energies (IFPEN)	Full professor	Focus group
#12	Society	Mobility issues	Heriot-Watt University (UK)	Associate professor	Focus group
#13	Society	Mobility issues	University of Nice-Côte d'Azur	Associate professor	Focus group
#14	Society	Mobility issues	VEDECOM Institute	Director	Focus group

Appendix B. List of the sources used for the assessment process based on the 18 criteria (see Table 1)

A. Economy

A1. Agence de l'Environnement et de Maîtrise de l'Energie (2015); Behaghel (2008); Boston Consulting Group (2016); CarSonar (2013); Chronos and L'ObSoCo (2016); Commissariat Général à l'Egalité des Territoires (2015); Mairie de Paris (2016); Transport public (2015, 2016b, 2016d, 2017a).

A2. 6-T (2015, 2017); CarSonar (2013); CEREMA (2016); COVIVO (2012); Transport public (2015, 2016c, 2017a, 2017b, 2017c); Visse (2013).

A3. 6-T (2015); Agence de l'Environnement et de Maîtrise de l'Energie (2015); ARCADIS (2016); CarSonar (2013); Mairie de Paris (2016); Transport public (2016d, 2017a).

A4. 6-T (2015); CGDD, DGE, PIPAME (2016); Honnart (2017); Mairie de Paris (2016); Sytral (2016); Transport public (2015,2016b, 2016d, 2017a, 2017b, 2017c).

A5. Transport public (2016d, 2017a, 2017b, 2017c).

A6. 6-T (2017); CGDD, DGE, PIPAME (2016); Cour des Comptes (2015); Mairie de Paris (2016); SNCF Réseau (2016); Transport public (2015, 2016d, 2017a, 2017b, 2017c).

B. Environment and health

B1 to B4. 6-T (2013,2015); Agence d'urbanisme pour le développement de l'agglomération lyonnaise (2010) ; Agence de l'Environnement et de Maîtrise de l'Energie (2015, 2016); Dantan et al (2015).

B5. 6-T (2013, 2017); Agence de l'Environnement et de Maîtrise de l'Energie (2015); European Railway agency (2014); MAIF (2015); Mairie de Paris (2016); Observatoire national interministériel de sécurité routière (2012).

B6. 6-T (2015); Agence de l'Environnement et de Maîtrise de l'Energie (2015); ARCADIS (2016); COVIVO (2012); Institut d'Aménagement et d'Urbanisme (2016); Observatoire Régional de Santé d'Ile-de-France (2012); Tansport public (2016b, 2017a).

C. Society

C1. 6-T (2013, 2015); Agence de l'Environnement et de Maîtrise de l'Energie (2015); Alternatives économiques (2015); CGDD, DGE, PIPAME (2016); Chronos and L'ObSoCo (2016); COVIVO (2012); Mairie de Paris (2016); Observatoire de la mobilité en Ile-de-France (2016); Transport public (2016a, 2016b, 2016d, 2017a, 2017b).

C2. 6-T (2015); Alternatives économiques (2017); Imarguerite (2011); Mairie de Paris (2016).

C3. 6-T (2013, 2015); Agence de l'Environnement et de Maîtrise de l'Energie (2015); Allinc et al (2018); Alternatives économiques (2015); Chronos and L'ObSoCo (2016);; COVIVO (2012); Créno (2016); Coeugnet-Chevrier et al (2019); Dantan et al (2015); Dusseaux (2016); IFOP (2017); Mairie de Paris (2016); Union des Transports Publics et Ferroviaires (2017).

C4. 6-T (2013, 2015); Agence de l'Environnement et de Maîtrise de l'Energie (2015); Chronos and L'ObSoCo (2016); COVIVO (2012); Créno (2016); Coeugnet-Chevrier et al (2019); Dantan et al (2015); Dusseaux (2016); Mairie de Paris (2014, 2016); Union des Transports Publics et Ferroviaires (2017).

C5. Chronos and L'ObSoCo (2016); Dusseaux (2016); Mairie de Paris (2014); Union des Transports Publics et Ferroviaires (2017).

C6. Chronos and L'ObSoCo (2016).

Appendix C. List of the selected mobility offers for the assessment process

Category of the offer	**Designation**	***Deployment Area***
Autonomous vehicle (shuttle)	Navly	*Local (Lyon, France)*
Bike-sharing (large city)	Vélib	*Local (Paris, France)*
Bike-sharing (medium city)	BIP	*Local (Perpignan, France)*
Carpooling (Inter- or multimodality in urban areas)	IDVROOM	*National (France)*
Carpooling (planned long-distance, driver)	BlaBlaCar	*International*
Carpooling (planned long-distance, passenger)	BlaBlaCar	*International*
Carpooling (planned short-distance, driver)	Citygoo	*National (France)*
Carpooling (planned short-distance, driver)	WayzUp	*National (France)*
Carpooling (planned short-distance, passenger)	Citygoo	*National (France)*
Carpooling (planned short-distance, passenger)	WayzUp	*National (France)*
Carpooling (real-time, driver)	Rydigo	*National (France)*
Carpooling (real-time, driver)	Oui'Hop	*Local (France)*
Carpooling (real-time, passenger)	Rydigo	*National (France)*
Carpooling (real-time, passenger)	Oui'Hop	*Local (France)*
Carpooling line (driver)	Fleetme	*Local (France)*
Carpooling line (passenger)	Fleetme	*Local (France)*
Carpooling line (periurban area)	IDVROOM	*Local (Lyon, France)*
Car-sharing (B2C with Public Service Delegation)	Autolib'	*Local (Paris, France)*
Car-sharing (B2C without Public Service Deleg.)	Autolib'	*Local (France)*
Car-sharing (C2C)	Ouicar	*National (France)*
Car-sharing (C2C)	Drivy	*International*
Car-sharing (long-term rental, owner)	Citroen TravelCar	*National (France)*
Car-sharing (long-term rental, tenant)	Citroen TravelCar	*National (France)*
Car-sharing (short-term rental, owner)	TravelerCar_airports_trainstations	*International*
Car-sharing (short-term rental, tenant)	TravelerCar_airports_trainstations	*International*
Micromobility (regular kick scooter)	Kick scooter	*International*
Micromobility (sharing syst., electric kick scooter)	Knot	*Local (Paris, France)*
Mobility app (multimodal information, internat.)	Google Maps	*International*
Mobility app (multimodal information, interurban)	Tuup *(Whim)*	*National (Finland)*
Mobility app (multimodal information, urban)	Optymod	*Local (Lyon, France)*
Mobility app (road route comparator)	Waze	*International*
Mobility app (smart parking)	Apila	*National (France)*
On-demand transport	Chariot	*Local (Wash. DC, US)*
On-demand transport	Flexo	*Local (Metz, France)*
On-demand transport	Bridj	*National (US)*
On-demand transport (airport shuttle)	Shaddl	*Local (Paris, France)*
Personal car (co-ownerhip offer)	Nissan Micra	*National (France)*
Personal car (electric power)	Single-occupant car driver *(electric)*	*International*
Personal car (thermal power)	Single-occupant car driver *(thermal)*	*Internat. (Reference offer)*
Private-hire (non pro., before 2016)	Djump	*Local (Paris, France)*
Private-hire (pro.)	UberX	*International*
Private-hire (pro.)	Lyft	*International*
Private-hire (shared)	UberPool	*International*
Public transport (interurban)	Ouibus	*National (France)*
Public transport (urban)	TCL	*Local (Lyon, France)*
Scooter (sharing system)	Cityscoot	*Local (Paris, France)*
Taxi (with mobile app)	Taxi G7	*Local (Paris, France)*
Taxi (without mobile app)	Taxi	*International*
Walking (regular)	Walking	*International*
Walking (co-walking)	MonChaperon	*National (France)*

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