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Abstract

In this article we seek to elaborate various sustainable mobility scenarios depending on heterogeneous geographical contexts. We use a multicriteria decision analysis (MCDA) to assess 50 mobility offers, relying on an original two-step assessment method. In a first step, we use the diviz decision-aid tool to obtain a global score for every offer, on the basis of 18 criteria that cover the three domains of sustainable development: economics, environment, society. In a second step, we use the MICMAC decision-aid tool to build relationships of influence and dependency between the 18 criteria. For each type of territory, we state what could be a development scenario for the future of mobility. Ultimately, an innovative hybrid mobility solution relies on the strengths and levers of the offers that were assessed, in response to the mobility scenario. We identify relevant solutions for dense and low-dense areas: in particular, carpooling offers reach particular efficiency in low-dense areas, combined with walking practices. Such combinations should be assisted by reliable multimodal mobility applications.

Keywords: multicriteria decision analysis, decision-aid tool, mobility offer, mobility usage.

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1. Introduction

Despite encouraging signs, new sustainable mobility offers still face psychological and sociological obstacles to behavior change (Buhler 2012, Créno 2016, Dantan et al 2017). For example, car-sharing is developing in large cities but it does not find its model in medium-sized cities (see for the example the defection in 2014 of the car-sharing service in the French city of Pau, 160,000 inhabitants). Similarly, while BlaBlaCar is a testament to the success of carpooling on long-distance planned trips, short-distance or real-time carpooling encounters difficulties (even if the two BlaBla lines launched in France in 2017 should be watched). Private-hire companies like Uber or Lyft seem to correspond to a strong expectation from mobility users, but only in very dense areas for the moment. A common feature of new mobility solutions is that they rely on Intelligent Transportation Systems (ITS), which “early adopters” use via mobility applications on their smartphone (Dantan et al 2015, CGDD DGE PIPAME 2016, Le Lab Chronos Ouishare 2017).

Historic offers like public transport have to adapt to maintain significant market shares, particularly in low-dense territories where they are currently struggling to provide efficient services (Le Boennec and Sari 2015). As for active modes (cycling and walking), they remain strongly dependent on urban planning designed to favor their attractiveness in the eyes of potential users. Moreover, the emergence of the “inclusive mobility” concept may provide mobility for everyone, independently of your age, physical capacity, gender or income (Deloitte 2017). This will not necessarily lead to the development of a new public transport offer. In this context, new offers need an evolution of the institutional context and will have to be taken into account in decision-making models.

At the core of this evolving pattern, single-occupant cars still ensure significant modal shares, including in central cities where the historic or emerging offers should encourage alternative usages. 73% of French people living in rural areas use their cars daily: it is not surprising given the few alternatives available in these sparsely populated areas. Still 54% living in cities with a population of more than 100,000 use their cars daily as well (Chronos/ L'ObSoCo 2016). Indeed, car is convenient in a number of situations (accompanying children, transporting heavy or bulky objects), and it offers shorter travel times than public transport in a non-congested environment. More generally, if not shared, car remains synonymous with autonomy and flexibility: you do not depend on anyone to travel. In return, car usage generates negative effects: it is an additional source of noise, air pollution, greenhouse gas emissions (GHG), congestion, road accidents... (Verhoef 1996). Public actors seek to limit such externalities in order to preserve a quality of life acceptable to residents (Le Boennec and Salladarré 2017).

The need for car and the lack of public finance since 2009 tend to attenuate the classic opposition between private car and public transit. Not surprisingly, the rehabilitation of cars is suitable for road federations (like Union Routière de France, URF 2016); it is a more unexpected position of the International Union of Public Transport (Van Audenhove et al 2014). Given the cost of implementing or developing public transit in medium to large cities, “car is the public transportation of tomorrow” may become a trendy slogan for public authorities, either as a complement or a substitute to public transit (see for example the Transdev offer of carpooling lines in several medium French cities, or the Chariot on-demand transport offer in the United States).

In this article we seek to assess existing or emerging mobility offers that could induce autosolists (single-occupant car drivers) to adopt sustainable mobility offers: public transport, active modes, and individual shared mobility: carpooling, car-sharing, private-hire, on-demand transport. We try to understand the features of exclusive single-occupant car-drivers. On the contrary we analyze the features of the 100% inter or multimodal users. How do these “early adopters” use mobile apps? Are these features transferable to larger groups? From the supply side, we seek to identify an innovative mobility offer (or a set of offers) to be developed on the relevant market, and to draw the conditions of economic durability for this (these) offer(s).

To answer those questions, we use a multicriteria decision analysis (MCDA) to assess a set of mobility offers launched in France, Europe or the US. We implement an original two-step method that we apply to 50 mobility offers. In a first step, we use the diviz decision-aid tool to obtain a global score for every offer, using 18 criteria that cover the three pillars of sustainable development: economics, environment, society. In a second step, we use the MICMAC decision-aid tool to build relationships of influence and dependency between the 18 criteria.

For each type of geographical context, we state what could be a development scenario for the future of mobility. We apply our two-step method to the specific case of the Ile-de-France region, where various types of geographical contexts may be found. We find that walking and carpooling usually constitute under-used mobility offers, and that mobility as a service (mobile apps) presents huge margins of progression in most of the situations.

The paper is organized as follows: in section 2 we focus on the interest of observing new mobility offers. In section 3 the need of geographical contextualization using a typology of territories is examined. A brief overview of the advantages of a multicriteria decision analysis is made in section 4. Our original two-step decision-aid tool is on the scope of section 5. Finally concluding remarks are provided.

2. The Observatory of New Mobility Solutions of the VEDECOM Institute

The Observatory of New Mobility Solutions that the VEDECOM Institute is developing is a decision-making tool for territorial authorities in order to propose a synthetic and clear presentation of the spatial planning modalities in terms of transport. It supports the development of mobility offers, facilitates animation and dialogue on these issues through the provision of data, statistics, analyzes and indicators. Once these indicators defined, the observatory is populated and maintained by the VEDECOM Institute.

This observatory is oriented on mobility offers in addition to existing observatories focused on users' behavior (eg Cetelem, Transdev or Keolis observatories in France). We propose to identify and analyze the new mobility solutions defined as any offer whose use is shared in time and/or in space.
This decision-making tool is targeted on gathering information data related to mobility offers (production of raw data as well as monitoring international best practices), in order to allow the territorial exploitation of these data (treatment and analysis of information on Mobility as a Service, or MaaS offers), to evaluate solutions (indicators and maps) as well as building different scenarios of territorial development in terms of mobility solutions.
This observatory is elaborated in a co-construction approach with experts in their field of activity (focus group methodology, Faucheux and Nicolai 2004a). It is composed of a set of indicators evaluating the impacts on a given territory.

The objective of this observatory is to prioritize the mobility solutions on a given territory (see paragraph 5.1. with diviz tool) and, secondly, to identify the variables that will be determinant for this territory in offering new mobility offers (MICMAC methodology application). In this context, we first have to decide what should be a relevant entry for a local authority for such prioritization. We retain the three pillars of sustainable development, as mobility policies are largely assessed on this basis at every level of governance: local, national and European. Then we define a typical user profile, retain a typology of new mobility offers and characterize a typology of territory.

As far as the *user profile* is concerned, we propose to characterize a user in relation to his behavior with regard to his mobility solution: personal or shared vehicle / individual or collective travel. We highlight two trends in order to justify our choice of this typology, "type of property" and "type of use":

- Socio-economic changes: rising life expectancy, populations with specific mobility needs ("young" retired, disabled, "vulnerable groups"), financial difficulties of households in relation to the weight of transport in the budgets, new consumption practices (freedom, utility, efficiency), the role of public transport, the management of commuting trips that are considered independent from each other...
- An evolution of the practices of individual mobility that offer combinations of choices between vehicle and travel: personal car trip/shared car, new consumption criteria (saving time, cross-border loading...). There is no more an average traveler, a typical day.

It is therefore necessary to analyze the needs of travel by taking into account feedback (see the different criteria of decision-making emphasized in Dantan and al 2017), increasingly complex mobility with multi-modality, inter-modality, co-mobility, on-demand transport, teleworking... in short, taking account flexible users. Such complexity derived from an evolving user profile is transcribed through several criteria we elaborate for the assessment of the mobility solutions.

For *mobility solution profiles*, we propose the following typology: mobility avoided (teleworking conditions), assisted mobility and agile mobility which ensures reactivity of solutions. We elaborate categories of mobility offers observing the solutions launched on the market (carpooling, car-sharing, public transport, active modes, private-hire, on-demand transport…). These categories are dynamic: when a new offer is launched, it may question the previous categorization (for example, the OuiHop offer launched in 2015 in the Ile-de-France region yields the creation of the “real-time carpooling” subcategory).

Socio-economic breakdowns appear in the practices of mobility. These changes are accompanying new societal trends: an expansion of the collaborative economy, users’ wishes to be associated with the definitions of product or service offerings (a strategic approach on user-centered innovation has to be reinforced), the rising of digital economy and connected objects, new labor organizations, a growing evolution towards a service economy (even if according to observatories of uses, the French people are still very attached to vehicle ownership).

Finally, we note that these new practices are highly dependent of the territories, which are themselves marked by strong inequalities in the provision of mobility services. Urban sprawl, increased multipolarity of territories (with a great diversity of travels), living areas with a wide radiance are as many sources of possible inequalities with regard to the provision of mobility services. This reflection on a necessary typology of the territories concerning the implementation of the mobility services will be addressed in the following paragraph.

The objective of this decision-aid tool is to identify mobility solutions that meet the major expectations of users:

- Simplicity of the mobility solution and guarantee of psychological comfort;
- Transparency of information so that experience feedback is as high as possible;
- Instant service: the availability of information in real time is a priority for many users;
- Door-to-door travel that has to be taken into account in route calculations.

The indicators that constitute the observatory respect main characteristics of a socio-economic dashboard. They were constructed to validate the following characteristics of any indicator (Faucheux and Nicolai, 2004b):

- Measurable: quantifiable (or qualifiable) using available tools and methods, in particular in terms of verifiable data;
- Robust: measurable constantly over time and in the same way by different observers in different areas;
- Relevant: for a given level of territorial precision, the availability of data in relation to the objective;
- Understandable: clear and shared definition of the indicator from an operational point of view;
- Sensitive: that needs to add information to decision-making.

We opted for a scorecard with 18 indicators (6 per sustainability pillar), with a comprehensible visualization that can be adapted according to the territory analyzed. The territorial specificities and their consequences in the choice of mobility solutions are the subject of a dedicated analysis which is presented in the following section.

3. Building a typology of territories

The manner a mobility solution may be deployed on a specific territory depends on its own socio-demographical characteristics. For example a car-sharing solution like Autolib may be efficient in the central city of Paris and the inner suburbs, but not necessarily in low-dense areas. The success of Uber is largely due to the short distances to be traveled that is to say, again, mainly in central cities. Before processing the evaluation, it thus appears to be particularly useful to build a typology of territories of close characteristics so that certain groups of mobility offers may be implemented here and not there, so they have a chance to develop a successful business model. For every criterion guiding the assessment process, the aim is to attribute specific weights for dense and low-dense areas.

To build an adapted typology of territories, we were assisted by five territorial experts: two academic ones (a researcher and an assistant professor in land sciences) and three operational experts in mobility policies working in public authorities (two medium-cities of the Paris conurbation). The result in the Ile-de-France region leads to five different types of territories that are specified regarding three variables: housing densities, employment densities and commuting flows between these two kinds of geographical spaces (Fig. 1). This original approach combines the institutional typology giving the physical frontiers between public authorities, and a morphological analysis built by the institute of land-use and urbanism of the Paris region (IAU IDF).

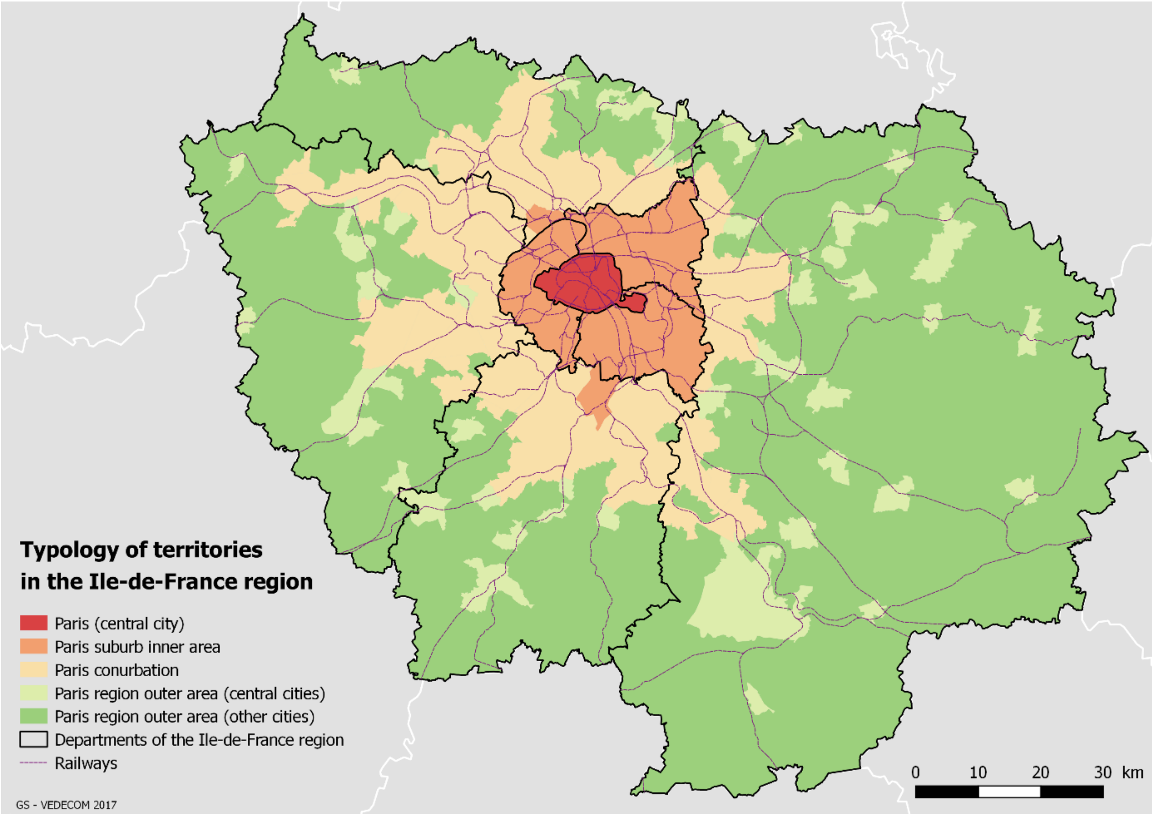

Fig. 1 Typology of territories in the Ile-de-France region

- *The central city of Paris*. Mobility policies should be designed at minimum on the scale of the "Greater Paris" (see level (2) below). However, the deployment of new offers starts in certain districts of the central city of Paris. As a corollary, even existing offers like taxis continue to be largely used in central cities, given the less distances to be traveled, compared with the rest of the suburb *(Population: 2,200,000)*.
- *Paris suburb inner area* or *Métropole du Grand Paris (MGP)* or *"Greater Paris"*. In these completely urbanized areas for long, bike or car-sharing networks are implemented to complete a historic mobility system along public transportation lines *(Pop. 4,800,000)*.
- *The Paris conurbation*. In these multipolarized but still urbanized areas, the public transport network remains dense. It allows travel easily to the central city or the inner area. Yet it appears to be difficult, given the larger area to be covered, to find shared mobility services without discontinuity *(Pop. 3,700,000)*.
- *The central cities of the Paris region outer area*. Several small or medium cities are served at least by one major transport network (mostly railway), whereas the rest of the mobility system is organized to switch users towards the train station in a radial manner.
- *The other communes of the Paris region outer area*. In these low-dense areas, it must be noticed a lack of governance of mobility. They may benefit from a service organized by larger mobility authorities and be the subject of local experiments (e.g. car-sharing offer in the Haute Vallée de Chevreuse, South West of Paris). However the implementation of a structured mobility policy remains problematic *(Pop. 1,300,000 including the last two categories)*.

4. Assessing new mobility offers to assist decision-makers

Every transport or mobility policy need to be assessed because of their costs and irreversible effects on a specific territory. Implementing a policy requires from the decision-maker to trade off between alternative projects on the basis of a number of considerations (International Transport Forum 2011). Will the project achieve its environmental objectives (air quality, GHG emissions, road safety, etc.)? Will it cost too much in relation to the expected benefits? Is it assessed on the right criteria? Is it preferable to another project? Formulated in economic terms, it is a matter of estimating the opportunity cost of a project.

To answer these questions, we mobilize a multicriteria decision analysis (MCDA), so that several criteria may be taken into account simultaneously (Munda et al 1995, Salling and Pryn 2015, Barbosa et al 2017). Cost-Benefit Analysis (CBA) makes it possible to take a decision in a context where the impacts of a transport project can be monetized (Quinet 2010). However there is a wide range of situations where the monetary value of a criterion may not be easily attributed, broadly speaking, the social or environmental dimensions (Joubert et al 1997, Tudela et al 2006). As a result, as soon as the evaluator refuses to put forward an (even imprecise) quantification of an impact, this impact cannot be taken into account in the assessment. Such an absence risks skewing the selection of the "good" project (International Transport Forum 2011). A multi-criteria decision analysis may thus be preferred by the decision maker (Beria et al. 2012, Hüging et al. 2014, Bueno et al. 2015). This type of analysis may prove relevant when considering the behavior of users and when favoring a broader approach than the calculation of social costs. A shared view is that a MCDA takes on more impacts into account, 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).

5. Application: the two-step decision-aid tool for the Paris region

5.1. The two-step decision-aid tool

Our methodological strategy pursues two complementary objectives: on the one hand, assessing mobility solutions one by one; on the other hand, developing a hybrid solution according to the type of territory.

The first step of the method is based on the comparison of various mobility offers in order to establish a ranking. For this first step, the diviz software is required (Meyer and Bigaret 2012, Cailloux et al 2013). A typology of new mobility offers is first established (see Section 2). We then retain the most representative offer(s) of each category, namely: first, the offer that regionally benefits from the highest number of users (e.g. BlaBlaCar for carpooling, Uber for private-hire or Google Maps for multimodal information app); and second, if relevant, an offer that presents some differentiation features compared to the leader, so that potential users in territories where the offer is not launched yet could benefit from it (OuiHop for carpooling, G7 taxis using a reservation app or the Finnish project tuup for multimodal information). 50 mobility offers are thus ready to be assessed. (Fig. 2a).

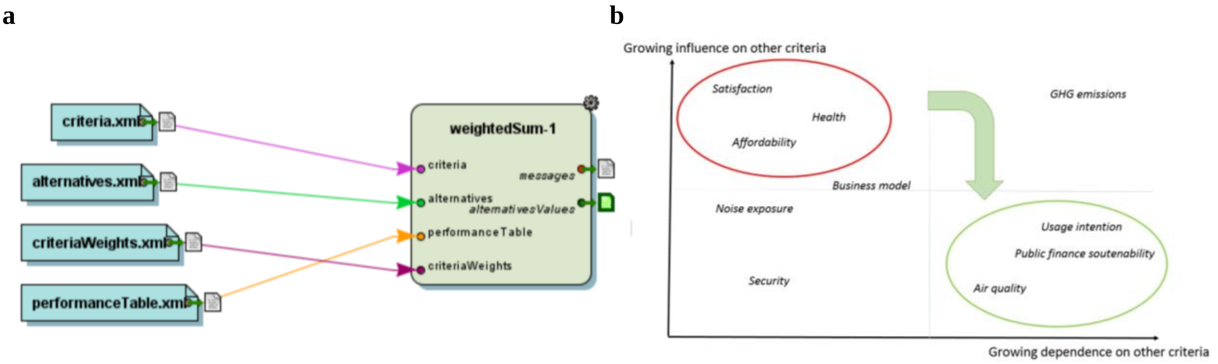

Fig. 2 (a) The diviz process for the assessment of 50 mobility offers (step 1); (b) Graph of direct influences and dependencies among criteria (step 2, example of the MICMAC use in this article)

The assessment process was based on a list of 18 criteria and measurement indicators (see Section 2). Six criteria are related to economic issues (both demand and supply), six other ones to environmental and health, and the last six to social or societal issues (incentives for use and effective usage, see Appendix A). To ensure the robustness of our proposal, it was planned by bringing the criteria and indicators to the validation of an expert group in mobility solutions: Nine qualified persons were invited in order to discuss the best criteria and indicators. Seven of these nine experts were external to the VEDECOM Institute. For each of the 18 validated indicators, the mobility offer was compared to single-occupant car usage (without definition of length or motive for travel).

The second step of the method consists in the production of mobility scenarios. We seek to build relationships of influence and dependence between our predefined variables (the 18 criteria). These relationships serve to state scenarios, which ultimately condition the design of hybrid mobility solutions. Thus, for each type of territory, a matrix of relationships between all the criteria taken in pairs is developed. The rating system ranges from "(0) no influence/dependence of variable 1 on variable 2 " to "(3) very strong influence/dependence of variable 1 on variable 2 ". A mapping of influential and dependent variables is proposed (example provided in Fig. 2b). The choice of the MICMAC software appears appropriate (Godet 2000, Shoai Tehrani and Da Costa 2017).

The y-axis in Fig. 2b shows an increasing degree of influence of variables as one moves from the bottom to the top of the graph (for example, the variable "Satisfaction"). Conversely, when one moves along the x-axis from left to right, one discovers variables more strongly influenced by the others (for example, the variable "Usage intention"). At the center of the graph is an area where the variables are neither significantly influential nor dependent on others (“Business model” here). Finally, in the northeast quarter of the graph are found the variables whose interactions between them appear significant and crossed. From this mapping, one or two prospective scenarios can be developed, based on variables that exert a strong influence (Shoai Tehrani and Da Costa 2017).

5.2. An illustration: the results of the first assessment step for the Ile-de-France region

The results obtained for the 50 mobility offers after the first-step of the method are the following (Fig. 3).

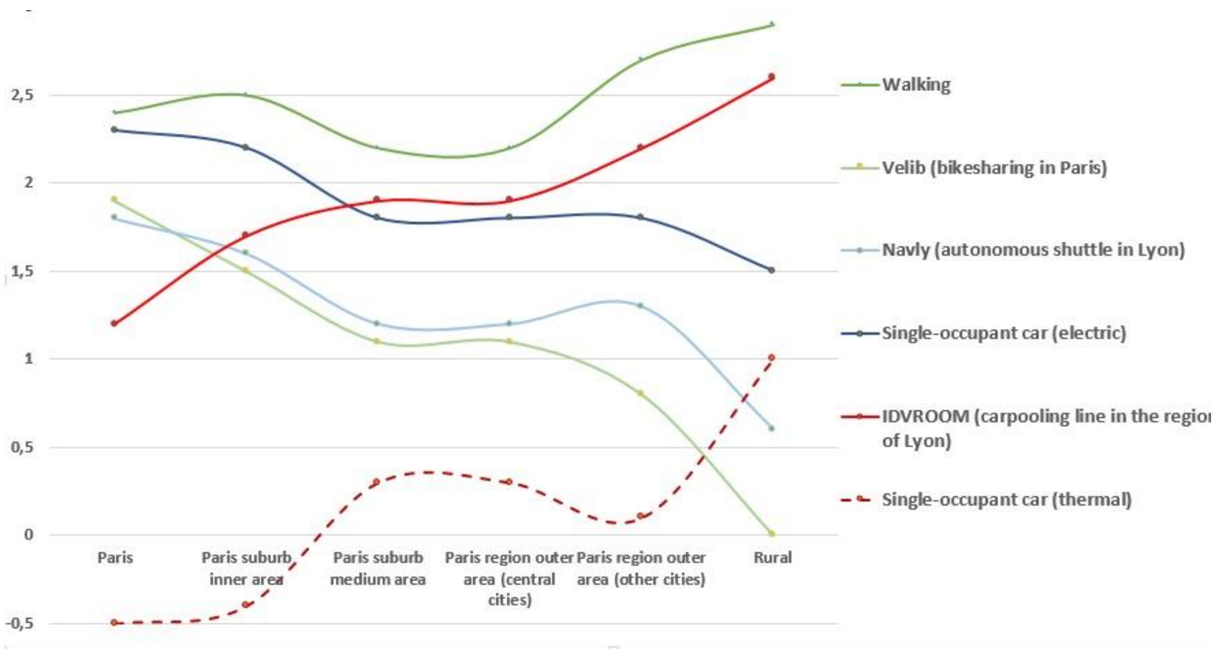

Fig. 3 Compared spatial performances of various mobility offers

The negative scores are the result of the weighting processes possibly giving scores below the average. We consider the sixth level of the typology of territories (“Rural”, out of the Paris region) so that the graph is more relevant. We retain the mobility offers with the highest scores before applying territorial weights, in comparison with the reference offer, namely single-occupant car with thermal power. We thus compare two active modes (walking and bike-sharing), two electric modes (one being experimental, the autonomous shuttle in Lyon, France), and one original carpooling offer (the IDVROOM carpooling line in the area of Lyon).

In dense areas, the thermal single-occupant car obtains very low results because of poor environmental results (air quality, noise emission). On the contrary in low-dense areas, the economic demand factors are massive and favor a high score (saved travel times, cars deployed everywhere independently from income). For comparable reasons carpooling offers follow the same pattern. These are good news for the enhancement of sustainable uses of cars.

Walking is the offer that obtains the highest score, every type of territory combined. This surprising result is due to economic factors (walking is costless for users), to the high scores obtained for environmental indicators (GHG emissions, air quality, noise emission, health), and to social or societal benefits (a universal mobility offer, convenient and inspiring security). The increasing tendency while the density decreases is due to the demand factor (economics issues) and the incentives to use (social and societal issues), whose weights increase while building density decreases. The tendency is opposite for the other active mode (Velib, the Paris bike-sharing offer), because of demand factors that obtain moderate scores: the offer is only available in rich dense areas.

We should notice a comparable pattern for autonomous shuttle: for this moment, travel times are still not competitive towards private car in low-dense territories (demand factor). Finally, electric car suffers from the lesser importance of environmental factors in low-dense areas, the other five scores obtained being quite homogeneous.

6. Concluding remarks

The overall results of our study are threefold:

- Carpooling offers present comparable patterns as single-occupant car use in various types of areas;
- Certain active modes, namely walking, should be promoted everywhere by public authorities. For example, the city of Montreal adopted the Charter of the pedestrian in 2006 which follows certain rules for future facilities: guaranteeing short travel times, comfort and security; ensuring easy access to commercial areas, ensuring safety for walking trips...
- In low-dense areas, walking should obviously be combined with other transportation modes. This would be enabled by the parallel high scores obtained by multimodal information apps (which are not represented here) that can help to fluid intermodal trips.

The way we processed to the assessment of the 50 mobility offers may be discussed; yet for every offer or group of offers we used reports that were published since 2012. The latter are not so numerous. They largely derived from ministerial sources, the French national institute for statistics and economic studies (INSEE), the French agency for environment and energy management (ADEME), or a few consulting companies (6-T, Chronos). That is to say it would be unlikely for different evaluators to obtain highly contrasted scores. Moreover we verified that our results were weakly dependent on the weighting strategies retained for the different types of territories.

Our two-step process is original. But even the first step of our study is not directly comparable to existing works. For example, ADEME frequently works on the evolving of groups of offers (carpooling, car-sharing, active modes, private-hire), but it does not compare these offers in the perspective of enabling a trade-off by a public authority. Mobility labs such as “La Fabrique des Mobilités” or “Le Lab OuiShare Chronos” are more like think tanks and/or incubators for mobility offers. They also facilitate professional relationships between new incomers and public authorities in an operational perspective.

The final stage of the project is the transformation of the mobility scenarios resulting from the second step of the method (the MICMAC process) into an innovative offer or set of offers. This or these offer(s) are expected to capitalize the strengths and levers of the offers assessed in the first step (the diviz process). A test of concept will ultimately aim at gathering the reactions of potential mobility users, the objective being to launch the offer by backing it to a durable business model.

The Observatory of New Mobility Solutions should be designed in a decision-making outlook for local authorities. Decision-makers should enter fine geographical and socioeconomic features of their territories, select the relevant criteria and apply adequate weights; this in order to assess various mobility offers which could be potentially beneficial for local needs. In the end, experiments could be conducted with voluntarist French urban communities, as far as they are concerned with coherent mobility management on their territory.

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Appendix

A.List of criteria and measurement indicators for the evaluation process

Domain	1. Economics					
Subdomain	Demand factors			Supply factors		
Criteria	1.1. Viability of the territory necessary to the implementation of the mobility offer	1.2. Cost of the mobility offer for user	1.3. Time savings allowed by the offer for user	1.4. Potential actors ready to get involved in the territory	1.5. Interoperability of the offer with the existing mobility system	1.6. 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) thermal single-occupant car	Average differential time compared to the fastest mode of transportation, including potential breaking bulks	Number of actors (automotive industry, local authorities) 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

Domain	2. Environment and health					
Subdomain	Energy - Global warming and air pollution			Other sanitary criteria		
Criteria	2.1. GHG emission abatement	2.2. Reduction of energy dependency	2.3. Improvement of air quality	2.4. Reduction of noise exposure	2.5. Improvement of road safety	2.6. Health benefits associated to the use of active modes (walking, cycling), in isolated use or
Indicator	Variation per traveler.km of GHG emitted by the offer compared to (personal) thermal single-occupant car	Variation per traveler.km of fossil fuels consumed by the offer compared to (personal) thermal single-occupant car	Variation per traveler.km of fine particles and nitrogen oxydes emitted by the offer compared to (personal) thermal single-occupant car	Variation at a given point of the mean noise level emitted by the offer compared to (personal) thermal single-occupant car	Variation per km travelled of the number of fatalities and injuries in circulation accidents compared to (personal) thermal single-occupant car	Does the use of the offer bring for user a cut in body mass index or in cardio-vascular accidents or in morbidity index, compared to (personal) thermal single-occupant car

Domain	3. Society					
Subdomain	Incentives for use			Effective usage		
Criteria	3.1. Conditions for territorial development of the mobility offer	3.2. Socioeconmic accessiblity of the offer	3.3. Collective levers and impediments for the use of the offer	3.4. Accessibility of the offer for vulnerable users (the elderly, disabled) and conditions of development towards other groups	3.5. Frequency of use of the offer	3.6. Satisfaction provided by the use of the offer
Indicator	Modality of co-construction of the offer with local conditions (safety, planning, infrastructure)	Does there exist a personal motive or a combination of personal motives favorable, from the user point of view, to the use of the offer? (combination of the three traditional personal motives of multimodality: a convenient and comfortable offer, affordable, inspiring confidence)	Share of collective motivations, from the user point of view, for 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 that used the offer at least once the year preceeding the survey	Satisfaction index concerning the mobility offer

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