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Rethinking transport
27–30 April 2020

Proceedings of 8th Transport Research Arena TRA 2020, April 27-30, 2020, Helsinki, Finland

Estimation of carpooling potential by trip modelling

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Abstract

The development of carpooling meets the challenges of sustainable development and energy transition. But prior assessment of the success of this transport service is complex. We propose a tool to estimate supply and demand potentials from a multimodal static agglomeration model. This is based on systematic exploitation of the model data. Indicators are created in order to quantify the attractiveness of a carpooling service, and the impact on the user in terms of cost and time. The tool is tested with the model of a large French urban area and a fictitious carpooling service. The results are presented with representations adapted to the qualification of the service. The method developed is a promising solution for the study of carpooling projects. Future work will deal mainly with modal shift and service reliability.

Keywords: transport planning; trip modelling; urban mobility; Mobility-as-a-Service.

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1. Introduction

Carpooling is one of the alternative means of transport to single-occupancy car use. It is one of the ways to reduce greenhouse gas emissions and optimize the use of road infrastructure. Even though this means of transport theoretically enables the number of vehicles travelling to be significantly reduced, it is very difficult to make a prior assessment of how successful a carpooling service will be. In particular, evaluating such a service involves identifying and quantifying users who may be attracted by this new mode of transport.
Despite significant potential in terms of people's changing mobility, there are many obstacles standing in the way of implementing carpooling and getting it to be accepted. The subject is a vast, complex one which often means that the problem is treated in fragmentary fashion in the scientific literature. Potential and expected shifts to the new mode have been investigated by Horowitz and Sheth (1977), Jacob Tsao and Lin (1999), Li et al. (2017).
Estimating carpool potential has featured in work based notably on coding of transport supply and demand in a geographical information system (GIS) and on systematic analyses. These analyses deal, for example, with optimizing the service in relation to the network, by Guidotti et al. (2017), identification of preferred stages or trajectories, by Czioska et al. (2016), Liu et al. (2016). An analysis was also conducted specifically on the potential of dynamic carpooling by Czioska et al. (2017).
Our work focuses on estimating the transportation capacity and the number of trips that a carpooling service can offer. It is based on the development of tools capable of using data from existing multimodal models to test carpooling projects. This is possible because static models of trips exist in certain urban areas. These give GISs that both contain a wealth of data and have a structure that is specifically oriented towards the study of mobility. We therefore propose to make use of these databases by building a method and indicators that can be used to take advantage of all the resources of static modelling.

2. Method

2.1. Data used

We based our work on the use of a multimodal static model of a large French urban area. This type of model is designed to replicate the movement of passengers and road haulage during morning and evening rush hours on an average business day. The urban area is divided up into zones whose size is inversely proportional to the population density.
In this case, we are interested only in morning rush hour (MRH). The useful data extracted from the static model are:

- indicator matrices calculated from zone to zone for travel times when roads are busy (during rush hours), toll costs, and the cost of using public transport (tickets);
- matrices for travel demand in a private vehicle (PV) as a driver N_{PVD}, in a PV as a passenger N_{PVP}, and in public transport (PT) as N_{PT}.

2.2. Description of the carpooling service tested

The carpooling service tested as part of this work is a "regular line" service. It does not require users to book in advance, but is based on a well-defined service. This type of service is very well suited for commuting, as such journeys are usually made during rush hour.
The present work concerns a MRH test of a regular car-pooling line in the urban area being examined, used to connect a park-and-ride (P&R) car park R located in a peri-urban area to an interchange point X corresponding to one of the existing P&Rs (as shown in Fig. 1).

2.3. Assumptions concerning user distribution in vehicles

Although the number of PV passenger users is known for each origin-destination relationship, the static model does not provide us with information about the distribution of the number of occupants on board the PVs. We must therefore associate these passenger users with drivers by hypothesis.
We therefore propose to use only two classes of PV usage:

- a first group consisting of vehicles with a single occupant (a driver);
- a second group consisting of vehicles with two occupants (a driver user and a passenger user).

In addition, we have chosen to ignore cases where PV occupation is greater than two users.

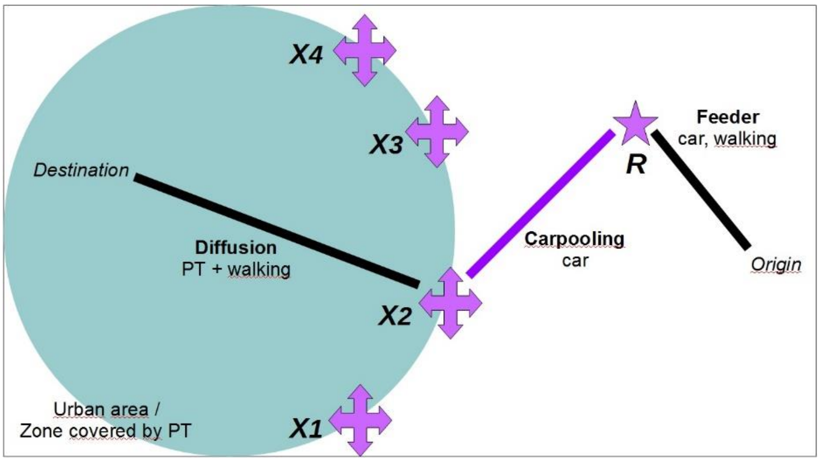


Fig. 1 Theoretical representation of the car-pooling trip (from the passenger point of view)

Consequently, we propose to define the "reservoir" that will be used as the basis for the carpooling offer and demand as the number of solo drivers, such that:

$$n_{solo\ drivers} = N_{PVD} - N_{PVP} \tag{1}$$

2.4. Calculation of the trip cost indicator

First, we assume that all users have the same value of time (VOT), and we set this to the central value defined in the static model used: €12/h. Next, we define the generalized time (GT) as the overall cost of travel that will serve as a basis for comparison between modes and between routes. For each mode used, we express this as the sum of the travel time during rush hour (busy period) and the cost of the journey converted into euro equivalent time, in cases where the journey requires payment of a toll or public transport ticket. This gives us, for a driver user in a PV, for a passenger user in a PV, and for a PT user respectively:

$$\begin{aligned} GT_{PVD} &= t_{PV,MRH}(o,d) + Toll(o,d)/VOT, \\ GT_{PVP} &= t_{PV,MRH}(o,d), \\ GT_{PT} &= t_{PT,MRH}(o,d) + Ticket\ price(o,d)/VOT. \end{aligned} \tag{2}$$

In fact, the GTs of intermodal carpooling trips were estimated on the basis of the GTs calculated on the existing modes. In particular, non-tangible impacts on the user of the shift to this new mode are not taken into account in this study. These impacts, positive or negative, may be psychological or sociological. In addition, we will consider that the origin points, the park-and-ride, the interchange points and the destination points are located on the centroids of the predefined zones in the static model. This is a restriction imposed by the way the latter operates.

2.5. Selection of driver candidates for the carpooling service

In order to build the panel of driver candidates (DCs) that can contribute to the carpooling service, we propose a selection rule to choose the origin-destination pairs on which a solo driver can change into a DC. This helps firstly to limit the number of possible cases to be tested, and secondly to keep only the most "favourable" cases.
We therefore propose the following hypothesis: the new carpooling route, with a passenger getting into the car at R and getting out at an interchange point X, will retain the origin O_D and destination D_D of the DC, but must not oblige the driver to turn back. This hypothesis is shown in Fig. 2a.

2.6. Selection of passenger candidates for the carpooling service

In order to build the panel of passenger candidates (PC) who can opt to use the carpooling service, we propose a selection rule making it possible to choose the origin-destination pairs on which a move from solo driver to PC is possible. As with the offer, this also makes it possible to limit the number of possible cases, and to target only the cases for which solo drivers are most likely to be PCs.

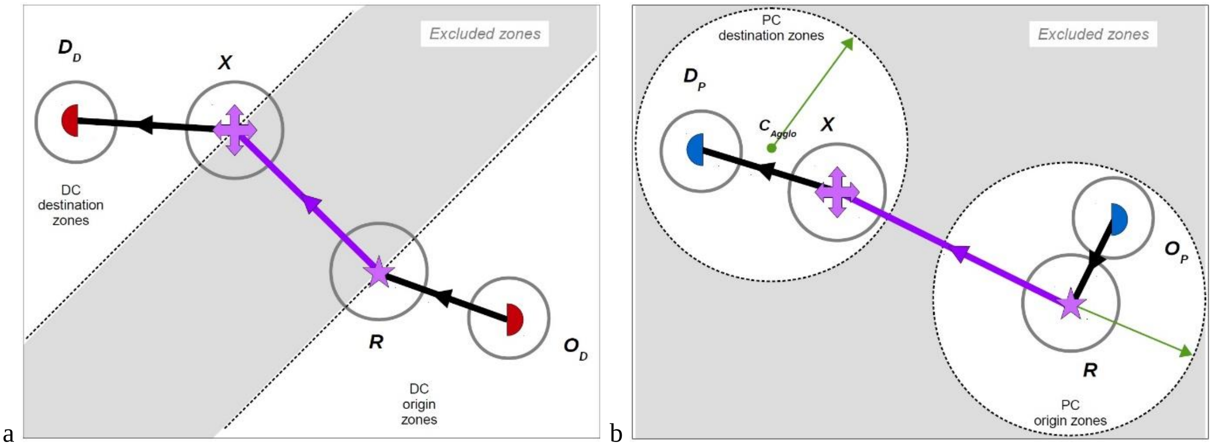


Fig. 2 (a) selection of DC origin and destination areas; (b) Selection of PC origin and destination areas

We therefore propose the following hypothesis: the new carpooling route, with passengers getting into the car at the P&R car park R and getting out at the interchange point X, will retain the origin O_P and destination D_P of the PC, but the use of carpooling determines positions O_P and D_P. The origin is located inside a first circular perimeter centred on the P&R car park R, which is the potential feeder perimeter. The destination is located within a second dependent circular perimeter centred on the heart of the urban area, which is the potential PT or walking distance from the interchange point X. This hypothesis is shown in Fig. 2b.

2.7. Individual attractiveness of the interchange points for the carpooling offer

In order to quantify carpooling offer between the P&R car park and an interchange point, we propose to count the DCs that can contribute to this offer during rush hour, i.e. those who are interested in dropping off a passenger at the interchange point X under consideration.
When DCs take part in the carpooling offer they systematically have to accept an increase in the GT of their journey compared to the direct route. We will call this increase the "detour" made by the DC. The greater the detour accepted by the DC, the greater the number of DCs.
We therefore propose to analyse the changes in the total number of DCs, from all origins and destinations, according to the maximum detour threshold. Knowing the interchange point X_i and the maximum detour threshold GT_{dmax}, the corresponding indicator will be expressed as:

$$N_{DC}(X_i, GT_{dmax}) = \sum_{O_D, D_D} p_{DC}\; n_{solo\,drivers}(O_D \to D_D)\, H\big(GT_{dmax} - GT_d(O_D \to R \to X_i \to D_D)\big) \quad (3)$$

$n_{solo\ drivers}$ the number of vehicles with solo driver, p_{DC} the proportion of solo drivers constituting the DCs, $GT_d(O_D \to R \to X_i \to D_D)$ the additional detour made compared to a direct route O_D to D_D. $H(x)$ is the Heaviside function, which is 1 if x is positive or null and 0 if x is negative.

2.8. Individual attractiveness of the interchange points for the carpooling demand

In order to quantify the carpooling demand between the P&R park and an interchange point, we propose to count the PCs that may make up this demand during rush hour, i.e. those who are interested in a carpooling trip between these two points as a passenger.
The shift of PCs to the carpooling offer systematically entails acceptance of a modification to the GT of their journey compared to the direct initial journey made in a PV. This "detour" made by the PC is of two types:

- if the detour is negative, the PC makes a GT saving by opting for carpooling, which gives him/her a real advantage;

- if the detour is positive, the PC makes a GT loss by opting for carpooling, which implies either acceptance, or compensation to offset the difference.

We therefore propose to analyse the changes in the total number of PCs, from all origins and destinations, according to the maximum detour threshold. Knowing the exchange point X and the maximum detour threshold GT_{dmax}, the corresponding indicator will be expressed in a similar way to Eq. (3):

$$N_{PC}(X_i, GT_{dmax}) = \sum_{O_P, D_P} p_{PC}\ n_{solo\ drivers}(O_P \rightarrow D_P)\, H(GT_{dmax} - GT_d(O_P \rightarrow R \rightarrow X_i \rightarrow D_P)) \quad (4)$$

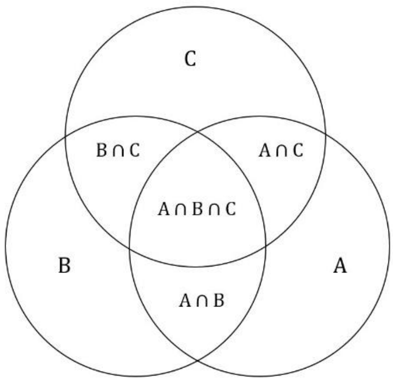
p_{PC} the proportion of solo drivers constituting the PCs, $GT_d(O_P \rightarrow R \rightarrow X_i \rightarrow D_P)$ the additional detour made compared to a direct route O_P to D_P.

2.9. Complementarity and relevance of the selected interchange points

After examining the attractiveness of each interchange point (considered individually) for the DC on the one hand and for the PC on the other hand, we can analyse the choice that may be made by the users with regard to the different interchange points which make up an overall intermodality offering across the urban area.

We hypothesize that, within a certain differential of GT gained or lost, two (or more) interchange points may be perceived by the user - driver or passenger - as “equivalent” in terms of the service rendered. Some users, therefore, do not choose one or the other exclusively but may be indifferently attributed to a set of interchange points.

In order to represent this analysis graphically, we propose to build Venn diagrams from the three most attractive efficient exchange points identified previously. The maximum number of three was chosen in order to make it easier to produce diagrams. In this case, such a diagram is similar to the example shown in Fig. 3, and makes it possible to divide the possible candidates over the seven possible cases of affinity with interchange points A, B, and C.



Interpretation:

A → the user is only interested in A;

A ∩ B → the user is indifferently interested in A or B;

A ∩ B ∩ C → the user is indifferently interested in the three points.

Fig. 3 Example of a three-circle Venn diagram

In such a diagram, we can then identify the number of candidates who are exclusively interested in a single interchange point, and the number of those who might use two or three of them. We can also analyse the relevance of simultaneously considering the three exchange points by answering the following questions:

- does an interchange point provide a sufficient supply/demand comparable to that of the other two?
- does an exchange point provide a significant supply/demand on its own and does it contribute to complementarity with the other two?

In particular, this analysis will highlight any weakness or redundancy of a point of exchange within the overall intermodality offering.

2.10. Number of potential users and carpooling trips

From the previous analyses, we estimate the carpooling potential through:

- the number of places available, equivalent to the number of DCs;
- the number of passengers produced by carpooling, equivalent to the number of PCs.

The number of trips made is obtained by comparing the two previous values. These potentials are dependent on the thresholds of user acceptability in terms of the additional cost (generalized time) that is inherent in carpooling. On the other hand, since the number of DCs and the number of PCs are estimated from the same "reservoir", we must ensure that $p_{DC}+p_{PC}\leqslant 1$ for any origin-destination relationship that is eligible for carpooling.

3. Results

3.1. Individual attractiveness of the interchange points for the carpooling offer

Fig. 4a gives a representation of the potential number of DCs, for each interchange point taken individually according to the GT differential (carpooling driver - solo driver). To make it easier to discriminate between the interchange points, we have considered the entirety of identified solo drivers (p_{DC}=1).

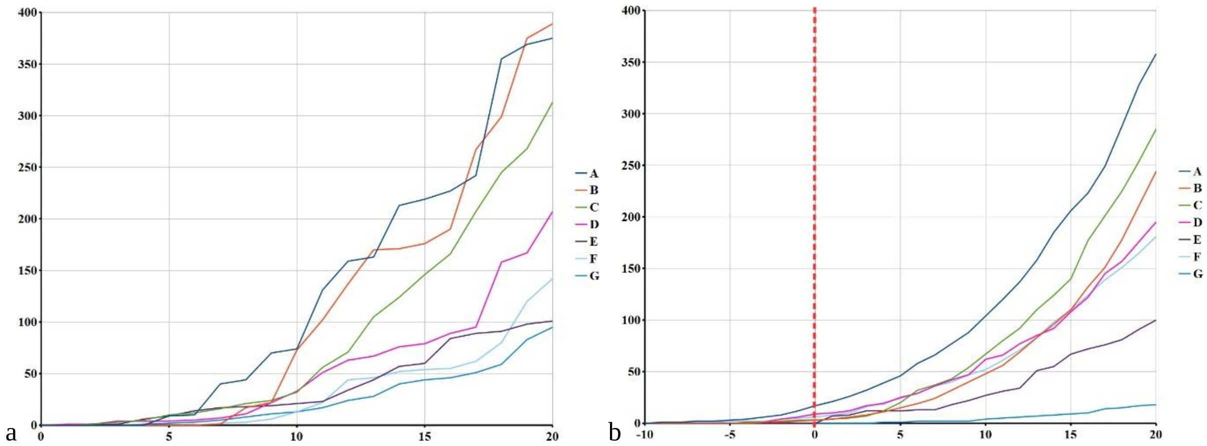


Fig. 4 Individual attractiveness of the exchange points expressed as a number of DCs in (a), PCs in (b), and according to the maximum detour accepted (in minutes)

We note that the detours observed are systematically positive: the DC automatically loses time if he/she opts for carpooling.
The attractiveness analysis shows that whatever the interchange point, the number of DCs is null if we aim for a GT gain. Carpooling does not provide any direct benefit in terms of travel time and cost for the DC.
To increase demand for the carpool service tested in our study, the average user must accept an additional cost for his/her journey. We deduce from this that designing an offer in terms of DCs also involves a certain compensation for this additional cost.

3.2. Individual attractiveness of the interchange points for the carpooling demand

Fig. 4b gives a representation of the potential number of PCs, for each interchange point taken individually according to the GT differential (carpooling passenger - solo driver). To make it easier to discriminate between the interchange points, we have considered the entirety of identified solo drivers (p_{PC}=1).
We note that the detours observed are divided into two possible cases:

- the first case, for which the detour is negative (to the left of the red dotted line): the user benefits from a GT saving on his/her journey;
- the second case, for which the detour is positive (to the right of the red dotted line): the user loses time due to choosing carpooling.

The attractiveness analysis shows that regardless of the interchange point, the number of PCs is low if we consider only the first case. Cases where carpooling provides a direct benefit in terms of time and cost of travel are very much in the minority.
To increase demand for the carpool service tested in our study, the average user must accept an additional cost for his/her journey. The finding is similar to that made for supply: designing a demand in terms of PCs also involves a certain compensation for this additional cost.
Although the attractive features of the interchange points A, B, and C are less noticeable than those of the other points, we still observe that the performance of these three is dominant.

3.3. Complementarity and relevance of the selected interchange points

Fig. 5 shows the potential choice of carpooling candidates for the three most attractive interchange points: A, B, and C. Such a Venn diagram representation makes it possible to distinguish the number of DCs (or PCs) opting for a single point, and the number of DCs (or PCs) leaving themselves the possibility of choosing between two or all three points.

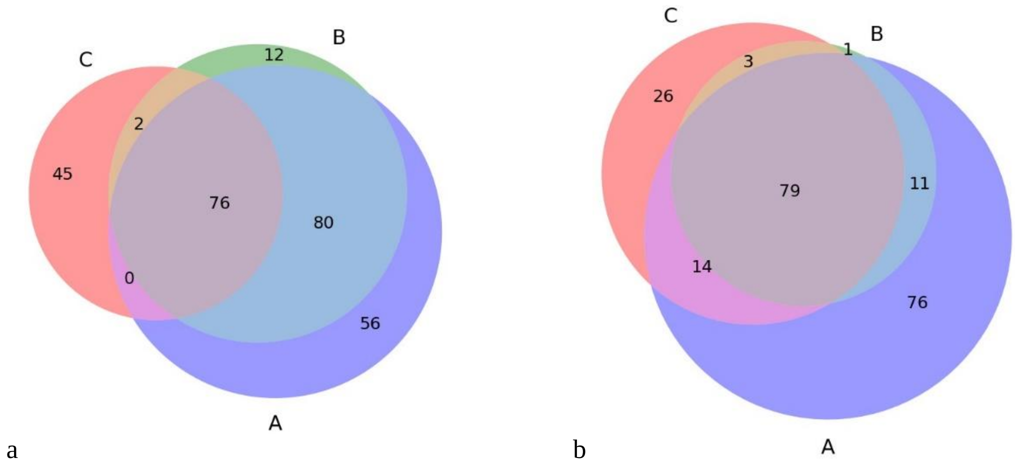


Fig. 5 Venn diagrams representing the size of the panels in number of DCs in (a) and PCs in (b) interested in one or more interchange points

In addition, the way in which the circles overlap makes it possible to analyse the utility of an interchange point. The larger the intersection areas between circles, the more redundant the services rendered by the points. Consequently, we can deduce that the supply (or demand) can be reduced to only two, or even a single interchange point.

In this case, the circles of A and B are almost overlapping. In addition:

- the number of DCs (and PCs) exclusively attracted by B is very small;
- the number of DCs (and PCs) interested in B is lower than the number of DCs (and PCs) interested in A.

From this analysis we can deduce that the interchange point B contributes little to the carpooling service tested. It can therefore be abandoned and the service refocused on points A and C.

It would be interesting to carry out a similar analysis to test the other points (D, E, F, G), in order to identify the cases that are significantly complementary with the pair A and C.

3.4. Number of potential users and carpooling trips carried out

To estimate of carpooling potential, it is possible to deduce from Figs. 5a and 5b the number of places available and the number of passengers using carpooling. These two values correspond, to the left and to the right respectively, to the sum of the users identified inside the coloured zones. The estimation of supply and demand is directly related to acceptance of the GT difference (ΔGT) imposed by choosing carpooling. To illustrate the impact of this difference, we can analyse the changes in supply and demand according to the maximum detour accepted. Table 1 gives estimates for a number of ΔGT values and the number of carpooling trips. In order to avoid double counts between DCs and PCs, we assumed the optimal case $p_{PC}=p_{DC}=0.5$.

Table 1. Estimate of the maximum number of trips allowed by the carpooling service, according to the acceptability of time lost by users.

		ΔGT for PC	- 5 min	0 min	+ 5 min	+ 10 min	+ 15 min
	Number of …	… passengers	1	7	22	53	107
ΔGT for DC	… places						
+ 5 min	3		negligible	negligible	negligible	negligible	negligible
+ 10 min	46		negligible	negligible	~20 trips	~50 trips	~50 trips
+ 15 min	137		negligible	negligible	~20 trips	~50 trips	~100 trips

4. Discussion

4.1. Application

The method proposed in this work provides a solution for approximate estimation of the level of carpooling supply and demand based on the many data contained in the static model. Such a tool enables rapid and systematic evaluation of projects and their impacts across an urban area. It can be used to guide choices for priority service in the new mode.

4.2. Problems to be solved

Several difficulties remain with regard to the operational application of this analysis tool. Evaluating a new mode of transport comes up against insufficient knowledge of the various factors attracting and repelling users.
In particular, this method deals with only part of the cost of travel. An analysis of a carpool service must include external factors such as any financial compensation, the virtual gain provided by the mode in terms of social and ecological contributions, and the psychological impact of abandoning “independent” solo driver status.

4.3. Possible solutions

Any financial compensation that may be paid to users can easily be included in the method to offset the additional cost of carpooling. However, converting this into generalized time requires precautions as to the choice of the value of time.
As far as consideration of more subjective factors is concerned, it is necessary to explore how users perceive the gains and losses caused by the change of mode. This appropriation involves:

- firstly, analysing existing carpooling services;
- secondly, analysing preferences expressed by targeted users during surveys.

5. Conclusion

At this point, we have succeeded in building a systematic method for estimating the supply and demand potential for carpooling on a regular line service. In addition to quantitative assessment of the target panel of users of this service, this method makes it possible to evaluate both the efficiency of existing intermodal interchange points, and the relevance of future dedicated infrastructure, such as P&R car parks, pick-up points, drop-off points, etc.
Our future work will focus on evaluating an overall offer for the entire urban area. We will be looking into automatic searching for optimal locations for P&R car parks. We will also be discussing the characterization of the carpooling system in terms of services rendered to the user, in particular to passengers opting for this mode of transport. In particular, we will be examining how to estimate waiting time in P&R car parks, which is highly dependent on the levels of supply and demand, and whether the user can also make the return trip by carpooling.
In addition, we will also be looking into the issue of modal choice which determines the transformation of a potential use of the service into an effective choice, i.e. real use of this new mode by solo drivers.

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