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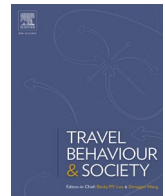
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# Assessing traveler compliance with the social optimum: A stated preference study

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## ABSTRACT

The development of Advanced Traveler Information Systems (ATIS) with en-route navigation systems has opened the door to new traffic regulation policies such as collective route guidance based on social costs, i.e. routes that minimize total travel time. However, a critical element for their efficiency is the compliance of travelers with route recommendations. It is well established that the social optimum is different from user equilibrium, where users drive on their shortest path. Thus, even when knowing that recommendations are for the common good, users may still choose not to follow the guidance given and drive as they wish. In this paper, we use a stated preference survey based on route choice situations from a real network to investigate traveler compliance for different levels of travel time sacrifice vs several social benefits. Two kinds of social benefits are considered: congestion alleviation and emission reduction. The data collected allows us to precisely quantify the travel time sacrifice that a given proportion of travelers would be ready to accept in order to take a different alternative that has a given level of social benefit. In line with the literature, our analysis confirms the decrease of compliance with the increase of sacrifice. Moreover, it suggests that the way the recommendation is intended could play a significant role in the level of compliance: the display of an advice message for the social path (in the congestion alleviation case) is shown to be more efficient than only showing additional information (in the emission reduction case).

## 1. Introduction

### 1.1. Literature review

Studying travelers' compliance with routing recommendations is not a new concern. It started in the 1990s when the concept of Advanced Traveler Information System (ATIS) emerged with the technologies of variable message signs and highway advisory radio. Numerous studies during that period investigated the behavioral responses of travelers to the provision of travel information, see [Schofer et al. \(1993\)](#) for a global review. Choice experiments in the laboratory using interactive computer simulation in particular gave more information on traveler motivation and compliance with ATIS ([Yang et al., 1993](#); [Adler and McNally, 1994](#); [Vaughn et al., 1995](#); [Mahmassani and Liu, 1999](#); [Adler, 2001](#)). Now that en-route navigation systems are a common feature of individual cars, this question has received renewed attention in the literature. The approach to the problem has also changed according to the characteristics and possibilities of new ATIS technologies: instead of being a general message to all drivers on a given road section, the route

recommendation can now be very specific to each user. While such individual-centered information can jam the network in a sub-optimal User Equilibrium (UE) state, it may also lead it towards a System Optimum (SO) if the ATIS technology is properly designed to favor system optimal routes, as shown in theoretical studies by [Dia and Panwai \(2007\)](#), [Colak et al. \(2016\)](#), [Klein and Ben-Elia \(2018\)](#), [Klein et al. \(2018\)](#), [van Essen et al. \(2019\)](#). A detailed review on choice and behavioral models and methods to understand the switch from UE to SO with travel information can be found in [van Essen et al. \(2016\)](#). This new approach of ATIS can, moreover, lead to the design of new control policies such as route guidance (as proposed in, e.g., [Oh et al., 2001](#); [Angelelli et al., 2016](#); [Wang et al., 2019](#)).

Since the 2000s, a large part of the literature has focused on traveler compliance with route choice modification when faced with travel information. Several factors, including travel time and network familiarity, congestion and incident occurrence, and driving conditions, were shown to have an influence on route decisions in laboratory simulation experiments ([Srinivasan and Mahmassani, 2000](#); [Chen and Jovanis, 2003](#); [Abdalla and Abdel-Aty, 2006](#)), driving simulator experiments

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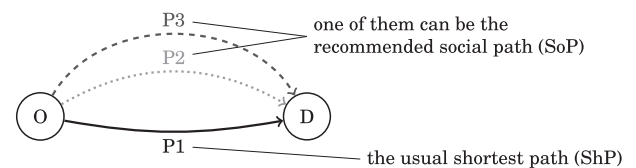
(Ardeshiri et al., 2015; Ringhand and Vollrath, 2017; Moghaddam et al., 2019), stated preference surveys (Jou et al., 2005; Khoo and Asitha, 2016), and revealed preference studies (Zhang and Levinson, 2008; Arentze et al., 2012; Ramos et al., 2012). Most of these works highlighted the importance of travel time reliability as a critical factor for travelers to trust and comply with information. In particular, Chorus et al. (2009) proposed a theoretical analysis of compliance as depending on information reliability and travel time uncertainty.

Among these works and more recently, some authors started focusing on routing recommendations that go against selfish individual goals, favoring social objectives such as congestion alleviation and environmental issues. Ben-Elia and Ettema (2011) showed with a field experiment that rewarding rush hour avoidance can be an effective tool to reduce congestion. Eriksson and Forward (2011) used a stated preference questionnaire to investigate the mode choice of travelers in relationship with their intention to preserve the environment. Kerkman et al. (2012) showed with an online questionnaire how drivers are willing to trade-off social objectives against individual goals if the advice they receive is labeled as personalized. The importance of the recommendation message was further confirmed by Djavadian et al. (2014), Ringhand and Vollrath (2018), Klein and Ben-Elia (2018), van Essen et al. (2018). As highlighted in these works, the compliance of travelers with social advice is higher when in-depth information is provided to them about the recommendation motivations and expected benefits, in comparison to a basic advice message. These studies also greatly contributed to the understanding of the trade-off travelers can make between their own interests and more socially desirable detours. In particular, van Essen et al. (2018) proposed a joint model from a questionnaire and a field experiment with revealed choices to analyze the impact of factors such as travel time and advice contents to explain the compliance of drivers towards a social optimum.

## 1.2. Research question and assumptions

In line with this literature review, this study aims at contributing to the following general question: Do travelers comply with the recommendation of socially desirable routes? But in contrast to the existing works mentioned above, in which generally only a global measure of compliance is given, in this study we focus on the detailed quantification of compliance to better identify when users stop complying with advice due to competition with other selfish goals. We also want to observe to which extent the level of expected social benefit can counterbalance selfishness. This leads to the following reformulation of our research question: What is the *sacrifice* that travelers are ready to accept to improve *social welfare*?

Here, we define the *sacrifice* as the relative increase of travel time a user expects to face by taking the recommended path instead of traveling on the shortest path. Although the users of a network are not necessarily traveling on the shortest possible paths in time between their origin and destination (Zhu and Levinson, 2015), it is however generally admitted that they tend to prefer shorter paths when the choice is explicitly given to them (see e.g., van Essen et al., 2019). This supports our definition of sacrifice with the difference in travel time with the shortest option. In addition, using a relative difference instead of an absolute one was suggested by Gonzalez Ramirez et al. (2020), as they showed that users tend to be more sensitive to relative differences in travel time rather than absolute ones. Whereas the experiments of Djavadian et al. (2014), Ringhand and Vollrath (2018), van Essen et al. (2018) used travel time differences of a few minutes maximum for the social detour, we want to go a step further by proposing longer trips with a travel time difference up to 50%, i.e. from 20 to 30 min in some cases. We also want to test multiple urban configurations with different origin–destination (OD) pairs and different total lengths. As for the notion of *social welfare*, we choose to focus on two major aspects: (i) the improvement of overall traffic flow (expressed as the reduction of total traveled time), and (ii) the reduction of CO<sub>2</sub> emissions. This splits the original question into two



**Fig. 1.** Path choice configuration with three options for a given OD pair. By convention, P1 is the shortest path (ShP) in time, and likely to be the usual path preferred by users, while P2 and P3 can be the recommended, so-called social paths (SoP), depending on the case.

sub-questions implying different social benefits. For the first sub-question, referring to the reduction of total traveled time allows quantifying congestion alleviation. For the second sub-question, we use a public transport alternative to show different levels of emission between transportation modes. Here also, our aim is to propose a wide range of total traveled time reductions and emissions to better identify the effect of these values in users' decisions when faced with considerable travel time sacrifices.

The remainder of this paper is organized as follows. Section 2 introduces the methodological framework of the route choice situation we consider. Then, in section 3 we present the experimental design and participant set used to collect the data. Section 4 deals with the experimental results, using a descriptive analysis and a Mixed Logit model. Finally, in section 5 a discussion on the findings of the study is presented.

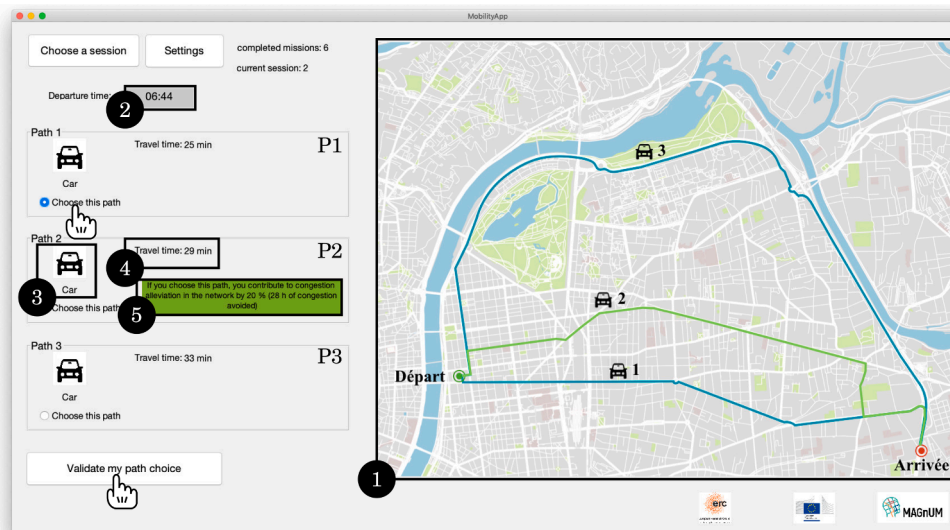
## 2. Methodology

A large number of path choice observations are required to draw significant conclusions on the evolution of compliance regarding both the travel time sacrifice and the level of social benefit. More precisely, we must bring together a large number of participants and control the levels of sacrifice and social benefit provided to them. For practical reasons, the use of a stated preference study was chosen over a revealed preference survey, which is very challenging and costly to carry out with enough participants and a wide variety of path choice conditions. Instead of a classical questionnaire proposing abstract and theoretical choice situations, we specifically designed our stated preference survey in the form of an application that automatically generates the choice situations (a similar principle can be found in the simulation experiments of Chen and Jovanis, 2003; Abdalla and Abdel-Aty, 2006). To improve the participants' immersion, they are based on a set of pre-defined paths of OD pairs on the map of the city of Lyon and Villeurbanne (France). A more detailed view of the application design is provided in the next section.

For each path choice, the following general framework is employed, see Fig. 1. Three paths, P1, P2 and P3 are proposed, whose expected travel times ( $TT_1$ ,  $TT_2$  and  $TT_3$ , respectively) are such that  $TT_1 < TT_2 < TT_3$ . P1 is thus the shortest path (denoted by the abbreviation ShP), and it is expected to be the usual choice of users if the travel time is the only information provided. This information is always given and serves as a measure of sacrifice. The travel time sacrifice  $\Delta TT_j$  of path  $j$  is written as follows ( $j = 1, 2$  or  $3$ ):

$$\Delta TT_j = \frac{TT_j - TT_1}{TT_1} \quad (1)$$

For the first sub-question (congestion alleviation), either P2 or P3 is recommended as the social path (abbreviated by SoP) to improve social welfare. The level of social benefit is indicated in a recommendation message as a given reduction of total traveled time (TTT in short) over the full network. This way of displaying advice is often called the *nudge* strategy in the literature (see e.g., Klein and Ben-Elia, 2018; van Essen et al., 2018). It was shown to have the highest impact on traveler compliance in these same studies. Here, the social benefit value  $SB_j$  of path  $j$  is simply the value of relative TTT reduction  $\Delta TTT_{red}$  given in the



**Fig. 2.** Screenshot of the application. A path choice situation is characterized by the following information: (1) map visualization, (2) departure time, (3) transport mode, (4) travel time and sometimes CO<sub>2</sub> emission, and (5) sometimes a recommendation message. The chosen path P1, P2 or P3 must be selected and then the choice validated.

message ( $j = 1, 2$  or  $3$ ):

$$SB_j = \begin{cases} \Delta TTT_{red} & \text{if } j = \text{SoP} \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

The settings are slightly different for the second sub-question (emission reduction). First, P3 is henceforth always considered as the social path by providing the new information on the CO<sub>2</sub> emission associated with each path (presented as emission per trip and per traveler). The recommendation is thus made in an implicit way: no special message is displayed with P3, it is simply the path with the lowest emission. Second, this path is presented as a public transport alternative (PT in short) to justify its lower emission compared to the car alternatives P1 and P2. In this case, the social benefit value  $SB_j$  of path  $j$  corresponds to the relative reduction of emission compared to P1 ( $j = 1, 2$  or  $3$ ):

$$SB_j = \frac{CO_{2j} - CO_{21}}{CO_{21}} \quad (3)$$

Finally, we also propose a new definition of traveler compliance in this paper. In the literature, the latter is often considered to be the proportion of choices which correspond to the recommended option (as in e.g., Kerkman et al., 2012; Djavadian et al., 2014; van Essen et al., 2018). While this definition appears relevant for evaluating the efficiency of a route guidance system, it can be seen as restrictive from a behavioral perspective, as it masks the prior preferences of users. In other words, when a choice is in accordance with an advice message, is it because the traveler was influenced by the advice when making their choice, or is it because they would have taken this alternative anyway? To overcome this limitation, we use a first route choice experiment without any recommendation, known as the control test, and compare it to a second route choice experiment where the recommendation information is given. We then define the compliance as the ratio of the number of users who changed their choices for the social path between the two experiments over the number of users who were previously traveling on the other paths (not that which would be turned into SoP) in the first experiment. Let us suppose that  $p_j^0$  is the proportion of users on path  $j$  during the first experiment and  $p_j$  the proportion during the second experiment (or, in a route choice context, the probability of taking path  $j$  without and with recommendation, respectively). Then, for the first sub-question (congestion alleviation), in the first experiment the proportion of users traveling on possible social paths is  $p_2^0 + p_3^0$  because either P2 or

P3 will be turned into SoP. In the second experiment, the proportion actually traveling on the social path is precisely  $p_j$  with  $j = \text{SoP}$ . Therefore, with our definition, the compliance  $\kappa$  is written as:

$$\kappa = \frac{p_{j=\text{SoP}} - p_2^0 - p_3^0}{1 - p_2^0 - p_3^0} \quad (4)$$

Similarly, for the second sub-question (emission reduction), in the first experiment the proportion of users traveling on possible social paths is  $p_3^0$ , as only P3 will be turned into SoP. In the second experiment, the proportion actually traveling on the social path is therefore  $p_3$ . Thus, in this case the compliance corresponds to:

$$\kappa = \frac{p_3 - p_3^0}{1 - p_3^0} \quad (5)$$

With this definition, the compliance  $\kappa$  lies in  $[0, 1]$ . Note that unlike most studies in the literature,  $\kappa$  does not represent the proportion of users traveling on the social alternative, but is more like a measure of the efficiency of the recommendation. A compliance of 0 means that no one changed their choices: the recommendation has no effect and is thus inefficient. A compliance of 1 means that all the users who were on other paths changed their choices and complied with the recommendation, so that everyone now travels on the social path: the efficiency of the recommendation is maximal. Compliance could actually be negative if the recommendation were to have a negative effect, but this is assumed unlikely to occur. This definition of  $\kappa$  also implies that for the same number of changes in travelers' decisions, a higher compliance is measured if fewer travelers are concerned by such decision changes (i.e. if more travelers naturally prefer the alternatives that are candidates for being the social path).

### 3. Experimental design

#### 3.1. Materials

Our stated preference study uses a Matlab application which automatically and successively generates path choice situations for the respondent. Each path choice situation corresponds to the general framework depicted in Fig. 1. The layout of the application is presented in Fig. 2, where the different elements characterizing a path choice situation are highlighted:

1. *The visualization of the OD pair with its three paths on the map.* For this experiment, a total of 14 OD pairs were selected on the network of Lyon-Villeurbanne (France). The selection was made to cover a wide range of path configurations and trip distances (from around 2 to 10 km). Part of these OD pairs are taken from [Gonzalez Ramirez et al. \(2019\)](#), and 4 representative pairs are shown in appendix. The OD pair proposed at each path choice situation is randomly picked from the OD set.
2. *The trip departure time.* A typical weekday morning was chosen, with departure times ranging from 6:30 to 11:30 am. The value proposed at each path choice situation is picked randomly in this range. The departure time influences the travel time information provided to participants (higher during a peak period defined between 7:00 and 9:00 am; more details are given further on in the article).
3. *The transport mode.* Two modes were considered: private car and public transport.
4. *The estimated travel time in [min] and the CO<sub>2</sub> emission in [g].* These two estimations are automatically generated for each path choice situation depending on the OD pair and departure time picked.
5. *The recommendation message to alleviate congestion.* This can be displayed for P2 or P3 only, while highlighting this path on the map. The text is always the same, except for the congestion reduction value automatically generated at each path choice situation: “If you choose this path, you contribute to congestion alleviation in the network by X% (Y hours of congestion avoided)”, ‘X’ and ‘Y’ being the given values of congestion reduction.

### 3.2. Design

One of the critical parts of the experiment was the design of the travel time, CO<sub>2</sub> emission and congestion alleviation information. This was done to be as realistic as possible, while ensuring a wide variety of situations for the result analysis.

For the travel time and CO<sub>2</sub> emission, the estimations given at each path choice situation are generated as follows. First, a mean value for P1 is used based on fixed mean speed and distance data for the current OD pair. For the car mode, the mean value was calibrated with Google Maps historical data in a preliminary study. The COPERT model ([Ntziachristos et al., 2009](#); [Lejri et al., 2018](#)) was used to estimate the CO<sub>2</sub> emissions. For the public transport mode, the mean value came from the Lyon public transportation network estimations, available on its online platform. Then, a peak hour factor was applied. It was calculated from a bell-shaped curve centered at 8:00 am to account for the morning rush effect at the current departure time. Finally, white noise was added to simulate natural variability in these quantities and ensure that they can be considered as continuous variables for the result analysis. The information given for P2 and P3, considered to be the first and second longer alternatives, came directly from the information given for P1. For the travel time, a factor randomly picked in [1.05, 1.25] was applied for P2, and another randomly picked in [1.25, 1.5] was applied for P3. For the CO<sub>2</sub> emission, when given, P3 was considered to be a public transport option, and therefore likely to show much lower emissions than individual cars. Again, to ensure a wide variety of situations, a factor randomly picked in [0.3, 0.9] was applied to the reference value given for P1. As P2 was still a car option, a factor randomly picked in [1.05, 1.25] was applied for this path.

Unlike the CO<sub>2</sub> emission values, the levels of TTT reduction were randomly picked from [0.05, 0.1, 0.15, 0.2] whenever the recommendation message for congestion alleviation was displayed. The absolute value of TTT reduction was also provided as an indication, calculated from a global estimation of TTT during peak hours in other simulation studies on this network.

### 3.3. Procedure

In order to study the influence of the different information on users’ decisions, the above-mentioned information was not always shown to

**Table 1**

The four sessions of the path choice experiment.

Path characteristics	Session			
	First sub-question on congestion alleviation		Second sub-question on emission reduction	
	1	2	3	4
ShP	P1	P1	P1	P1
SoP	–	P2 or P3	–	P3
PT	–	–	P3	P3
Travel time info	All paths	All paths	All paths	All paths
TTT red message	–	SoP	–	–
CO <sub>2</sub> info	–	–	–	All paths

**Table 2**

The participant set.

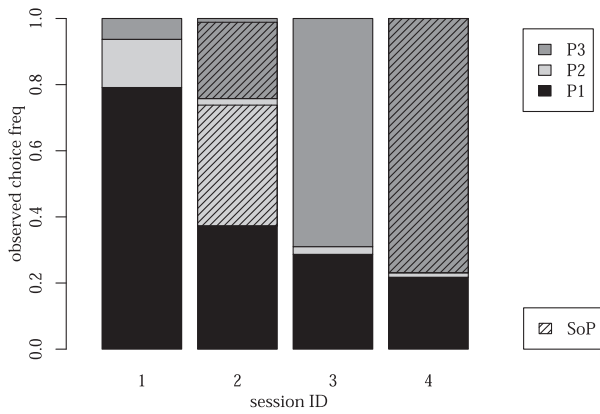
Category		number	[%]
Social category	Active	90	67.67
	Student	36	27.07
	Retired	7	5.26
Age category	18–29	55	41.35
	30–39	33	24.81
	40–49	24	18.05
	50–59	12	9.02
	60–69	8	6.02
	70+	1	0.75
Regular driver?	Yes	76	57.14
	No	56	42.11
	Prefer not to answer	1	0.75
Familiar with the network?	Yes	99	74.44
	No	33	24.81
	Prefer not to answer	1	0.75

them. The experiment was thus split into four successive sessions, as presented in [Table 1](#). The travel time information was given in all sessions. Sessions 1 and 2 referred to the first sub-question on congestion alleviation. Session 1 was the control test experiment (without recommendation), and session 2 included a recommendation on either P2 or P3 for each path choice presented to the participant. As shown in [Fig. 2](#), this new information was given by highlighting the social path and displaying the recommendation message with the value of TTT reduction. Sessions 3 and 4 referred to the second sub-question on emission reduction. Then, P3 was shown as a public transport alternative with the transport mode icon, see also [Fig. 2](#). Session 3 was the control test (with only travel time information), and session 4 included the additional CO<sub>2</sub> emission information on all paths. As a public transport option, P3 had the lowest emission and was thus implicitly defined as the social path.

The application was installed on a laptop provided to each participant. Before they started the experiment, instructions were given on the successive sessions about the information they would receive. In all sessions, the travel time was said to be a reliable estimation based on historical data such as those provided by Google Maps. In session 2, the congestion alleviation was presented as the prediction of a centralized control system which would not impact the current situation, but would improve overall traffic conditions in the short term if everyone complied with their own personalized recommendation. In session 4, the CO<sub>2</sub> emission was said to come from the Lyon public transport online platform, coupled with our own estimation methods. Each participant was reminded that they were free to trust the information or not, and could use their own knowledge about the network to take their decisions.

### 3.4. Participants

133 participants were recruited from October to December 2019. The respondents included colleagues at university, students, family, friends and also people recruited externally following an advertising campaign. The participants answered the study on a single computer,



**Fig. 3.** Observed path choice frequency in the four sessions. In session 2 and 4, the proportion corresponding to the choice of the social path (SoP) is displayed by the hatched lines.

with the assistance of a lab member to ensure they understood each path choice situation correctly. Because of the limited number of available laptops with the application installed on them, multiple appointments were organized over almost 3 months to collect the data. Although most of the participants were from well-educated social classes, the recruitment was carried out to ensure enough heterogeneity regarding age, social/activity categories and other attributes, as detailed in Table 2.

Note that the panel was not representative of the French population, but was relatively diverse and covered a wide range of situations. Before starting the experiment, the respondents filled a consent form mentioning that they participated of their free will and accepted the use of their responses for a scientific study and publication. To reward their participation, they were invited to a lottery to win a tablet from a well-known technology company.

The participants were asked to complete the four sessions successively. In each session, they had to indicate their preferred path for the multiple situations generated by the application for them. On average, each participant made 32 path choices per session, thus 128 choices for the four sessions. With all the participants, each session gathered around 4300 choice observations, thus around 17,200 observations for the four sessions.

## 4. Results

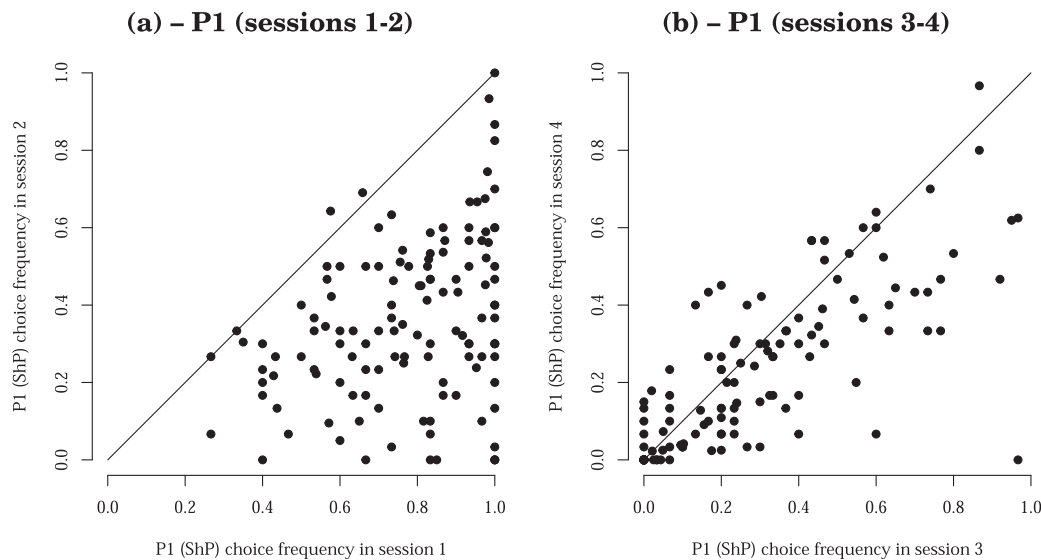
### 4.1. Descriptive analysis

#### 4.1.1. Global path choice frequency

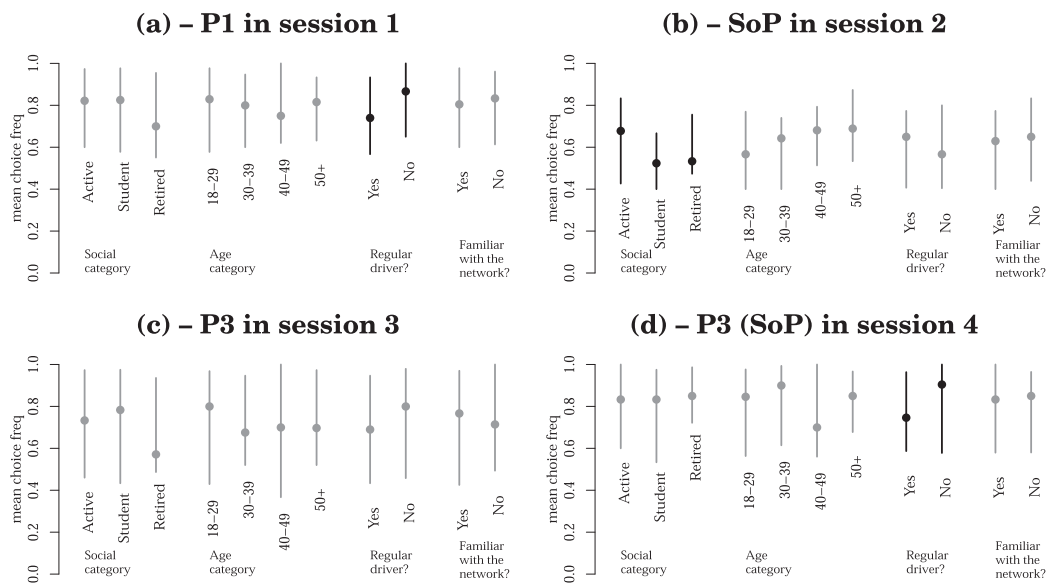
The path choice frequency observed (proportion of the participants' choices for a given path) is presented for the four sessions in Fig. 3. In sessions 2 and 4, the share of the proportion corresponding to choices for the social path are indicated by hatched lines. We first analyze global choice frequencies regardless of the participant who made them (every respondent made several choices in each session).

Let us focus on the first sub-question on congestion alleviation. In session 1, almost 80% of the participants' choices were P1 with only the information of the city map and travel time. This confirmed our assumption about the shortest path being the most preferred path in this situation. In session 2 however, the effect of the advice message was clearly visible, as now more than 60% of all decisions were in favor of the social path. With 4844 observations in session 1, and 4110 in session 2, the difference of choice proportions for the three paths between these two sessions was significant ( $\chi^2 = 1640$ ,  $DF = 2$ ,  $p\text{-value} < 0.0001$ ). Global compliance with following a detour to alleviate congestion can be calculated with Eq. 4:  $\kappa = 0.49$ . This value is lower than the proportion of SoP choices as it accounts for the share of decisions that were not for the shortest path P1 in session 1.

The situation is quite different with the second sub-question on emission reduction. In session 3, it appears that most choices were for P3 (slightly less than 70%), the public transport alternative. Knowing that most choices were for P1 in session 1, and that the only difference between sessions 1 and 3 was the new mode for P3, this expressed a clear mode preference in our sample of respondents. Nevertheless, the effect of the additional CO<sub>2</sub> emission information was visible as even more choices were for P3, considered as the social path in session 4 for its lower emissions. With 4206 observations in session 3, and 4189 in session 4, the difference of choice proportions for the three paths between these two sessions was also significant here ( $\chi^2 = 64.5$ ,  $DF = 2$ ,  $p\text{-value} < 0.0001$ ). Global compliance with reducing emissions can be calculated with Eq. 5:  $\kappa = 0.25$ . This was half the compliance in the first sub-question (sessions 1 and 2), although a higher proportion of SoP choices was observed in session 4 in comparison to session 2. This is explained by the natural preference for the public transport alternative even when the emission information was not given (session 3). The fact



**Fig. 4.** Choice frequency of participants, comparison between sessions. (a) P1 choice frequency in session 2 vs session 1, (b) P3 choice frequency in session 4 vs session 3. The Wilcoxon signed-rank paired test indicates that there is a shift in the proportion of choices for the fastest route between sessions with  $p\text{-value} < 0.0001$ .



**Fig. 5.** Path choice frequency of participants gathered by category: (a) P1 (ShP) in session 1, (b) SoP in session 2, (c) P3 (public transport) in session 3, and (d) P3 (SoP-public transport) in session 4. Each distribution is shown by its median and 20th–80th percentiles. Distributions from a given category are displayed in black if they were found statistically different (95% confidence) according to the Kruskal–Wallis *H*-test.

that P3 was presented as the social path with additional information on all paths and not with a unique advice message may also have played a role, but the design of our experiment did not allow us to conclude on this point.

#### 4.1.2. Shift in the choices of participants

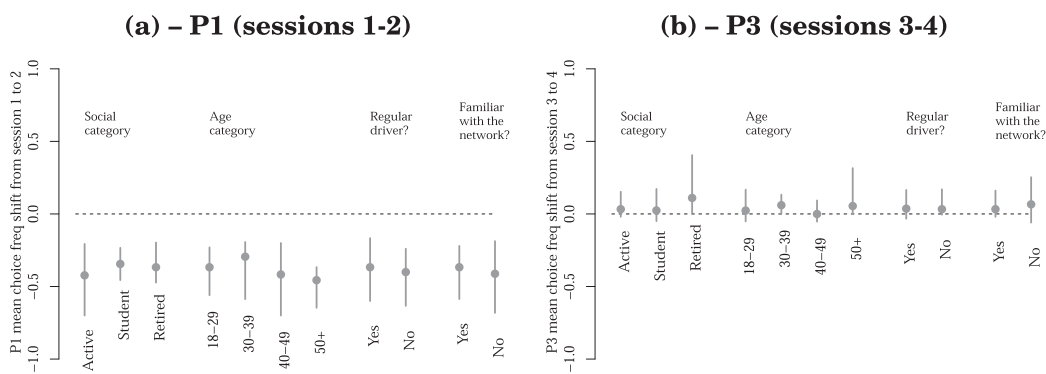
We provide further evidence on how the participants decisions were influenced by the information about the social routes. In contrast to the previous section where the choices were analyzed globally, here we analyze the changes in the choices by participant. The analysis is based on the changes in the choices for the fastest route between sessions 1 and 2, and between sessions 3 and 4. The results are presented in Fig. 4, where a clear change can be observed for sessions 1 and 2: when the social path message is given (session 2), participants chose less the shortest path. A similar though less strong trend is observed between sessions 3 and 4. To formalize the analysis, a paired difference test (Wilcoxon signed-rank test) is performed on the differences  $\hat{p}_i^{(S2)} - \hat{p}_i^{(S1)}$ , where  $\hat{p}_i^{(Sk)}$  is the observed proportion of choices of participant *i* for the shortest path in session *Sk* and the null hypothesis is *H0: Location shift equal to zero*. For both cases, sessions 1–2 and 3–4, we have that *p*-value < 0.0001, so the null hypothesis can be rejected with high confidence,

concluding that there is a shift in the proportion of times that participants chose the fastest route between sessions.

#### 4.1.3. Participants' choices by category

The participants' choices were further analyzed by distinguishing them by category. Their categories were introduced in Table 2 in the previous section. Now, the analysis is centered on the choice frequencies of each participant in the four sessions.

Fig. 5 presents the distributions of each participant choice frequency for a given path in a given session. The distributions are shown by participant category, with a point for their median and a line that spans from their 20th to 80th percentiles. The distributions for a given category are displayed in black when they are found to be significantly different, i.e. with a *p*-value below 0.05 in the Kruskal–Wallis *H*-test (Kruskal and Wallis, 1952). In Fig. 5(a), we see that regular drivers are more likely to take the non-shortest path options than non-regular drivers. This corroborates the finding of Adler (2001) regarding the perception of travel information; experienced drivers are less likely to trust informed travel times. Interestingly, we notice in Fig. 5(b) that older regular and active drivers are more willing to choose the social path in session 2, as opposed to younger students. Although this



**Fig. 6.** Shift in path choice frequency of participants gathered by category, from one session to another. (a) Shift observed in P1 (ShP) choice frequency from session 1 to 2, and (b) shift observed in P3 (public transport) choice frequency from session 3 to 4. Each distribution is shown by its median and 20th–80th percentiles. Distributions from a given category are displayed in black if they are found to be statistically different according to the Kruskal–Wallis *H*-test.

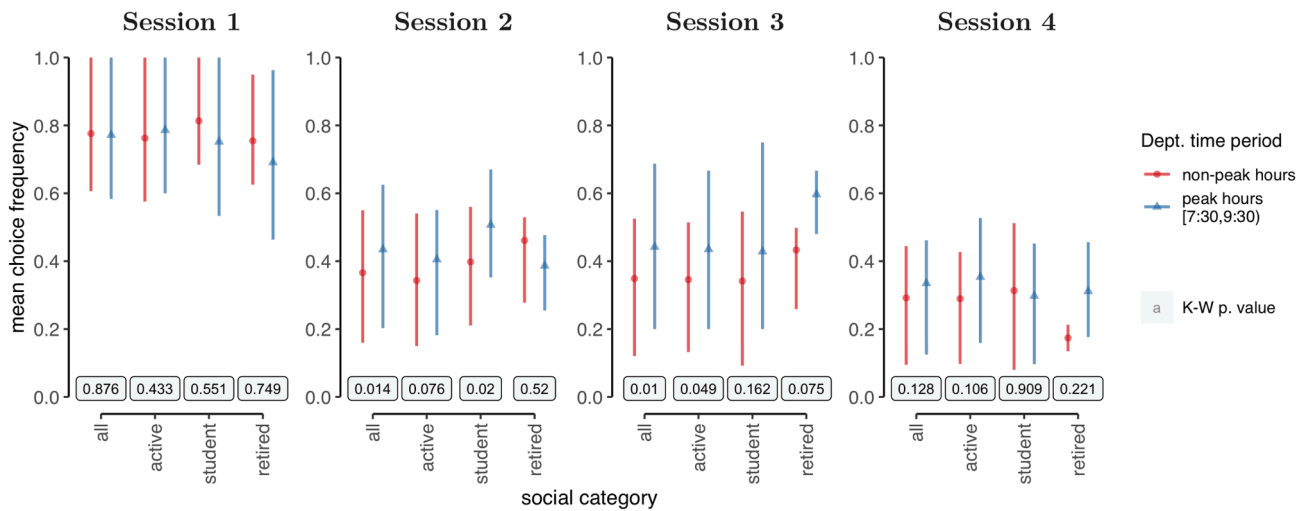


Fig. 7. Distribution of the proportion of fastest route choices by departure time period and social category. The mean of the distribution is represented with the point and the bars indicate the first and fourth quintiles. The Kruskal–Wallis H-test p-values are presented at the bottom of the plot.

comparison was not found to be completely significant, it is a quite unexpected and optimistic behavior observation. Stronger evidence from a revealed preference study would be required to further understand the motivations of these different driver categories. Regarding this topic, some insights can be found in van Essen et al. (2018). In Fig. 5(c) and (d), interesting observations can be made on mode preference. Young students (most of them probably not owning a car) tended to prefer public transport more than others, whereas regular drivers were less likely to take this alternative when compared to others.

Fig. 6 presents the distributions of each participant difference in choice frequency for a given path between two sessions. As previously, the distributions are shown by participant category, with their median and their 20th and 80th percentiles. The distributions for a given category are displayed in black when they are found to be significantly different according to the Kruskal–Wallis H-test. Fig. 6(a) represents each participant choice shift for the shortest path P1 from session 1 to 2. The negative values denote a lower number of P1 choices from the participants in session 2, as described previously. Interestingly, there is a shift in the high (absolute) values of choice frequency (down to  $-0.7$ ) for some users, especially among active people. This suggests that the effect of the recommendation message can be very strong on some travelers, as it completely modifies their path choices. The choice shift for the public transport alternative P3 from session 3 to 4 is illustrated in Fig. 6(b). As mentioned earlier, the effect of the CO<sub>2</sub> emission information in session 4 is less visible as the choice shift for P3 is much lower, in comparison to the recommendation effect in session 2. But in both cases, our panel data

is probably too small to highlight significant differences between the categories regarding choice shift.

#### 4.1.4. Participants' choices by departure time of the trip

The departure times in the experiment take place between 6:30 and 11:30 in the morning. In this analysis, we define the peak hours as the period running from 7:30 to 9:30 and we analyze the percentage of choices for the fastest route (ShP) for peak and non-peak hours (Fig. 7). In general, participants show a slightly higher preference for the fastest routes during the peak hours, although the Kruskal–Wallis test resulted significant (95% confidence) in only five of the analyzed cases. From all the social categories, active participants are those who show the clearest trend, preferring the fastest route during the peak traffic hours in the four sessions. This suggests that choosing a social path is constrained by the activity starting time, which in the case of the students and retirees is more relaxed. In session 3, where a PT alternative is available, a preference for the fastest route during rush hours is noticeable for all social categories, indicating a preference for a faster mode of transportation or car mode during the rush hours. Nonetheless, in session 4 the difference in the choices between departure time periods is shortened, suggesting that informing travelers of the CO<sub>2</sub> emissions could be effective in changing mode choice behavior even during the rush hours.

#### 4.1.5. Observed compliance

The global compliance levels for the two sub-questions were given earlier, but now the aim is to observe the evolution of compliance for

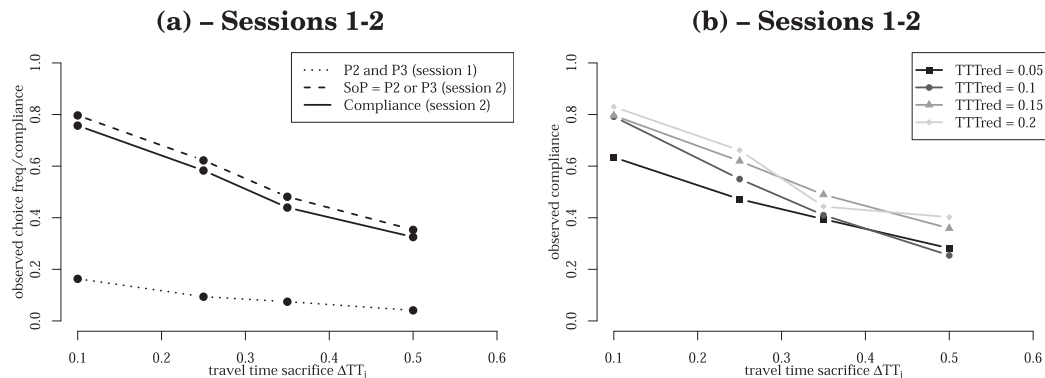


Fig. 8. Compliance for the first sub-question addressed by sessions 1 and 2. (a) Global compliance for the social path ( $j = \text{SoP}$ ), and (b) compliance by value of social benefit (relative reduction of total traveled time).



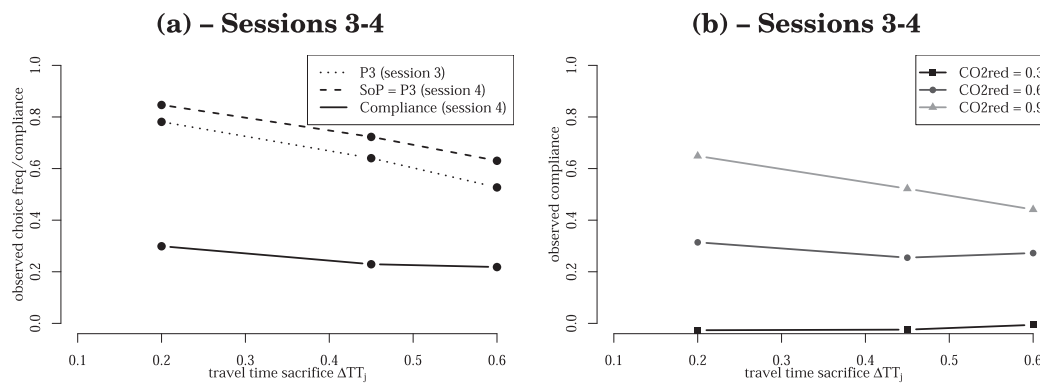


Fig. 9. Compliance for the second sub-question addressed by sessions 3 and 4. (a) Global compliance for the social path ( $j = \text{SoP}$ ), and (b) compliance by value of social benefit (relative reduction of  $\text{CO}_2$  emissions).

different levels of travel time sacrifice and social benefit. Hence, the choices of participants are aggregated with respect to similar intervals of sacrifice and benefit.

For the first sub-question on congestion alleviation, Fig. 8(a) presents the compliance in session 2 (solid line) as calculated with the social path choice frequency in session 2 (dashed line) and the observed choice frequency of P2 and P3 in session 1 (dotted line), see also Eq. 4. Four values of choice frequency are calculated for four intervals of travel time sacrifice (each dot corresponds to the middle of each  $\Delta TT_j$  interval). We used only four points to ensure enough observations in each travel time interval to obtain a reliable measure of choice frequency. As expected, the compliance decreases as the sacrifice increases, but several key observations are noteworthy. First, we noticed very high compliance (almost 0.8) for a low sacrifice ( $\Delta TT_j$  around 0.1). This can be interpreted in the light of the Bounded Rationality theory (Simon, 1955): easily accepting a path change at a low cost may denote an indifference or satisfying behavior. Second, the decrease of compliance is surprisingly almost linear. Nevertheless, a quicker drop in compliance is visible around  $\Delta TT_j = 0.3$ , which may suggest a threshold where the sacrifice starts overcoming the social benefit. The compliance is reduced by half when the travel time of the social path is around 50% higher than that of the shortest path. Fig. 8(b) depicts the same compliance evolution but now distinguished by the social benefit level displayed in the recommendation message (TTT relative reduction  $\Delta TTT_{\text{red}}$ ). Overall, we observed higher compliance for a higher benefit, which was in line with expectations. However, an interesting trend is worth mentioning. For low sacrifice ( $\Delta TT_j$  around 0.1), the benefit value plays a significant role from  $\Delta TTT_{\text{red}} = 0.05$  to 0.1, but is irrelevant for higher TTT reductions, meaning that the advice itself seems more important than its contents at this point. This is also the case for a sacrifice above  $\Delta TT_j = 0.3$ , where the benefit values of  $\Delta TTT_{\text{red}} = 0.05$  to 0.1 lead to the same compliance level. However, higher values of  $\Delta TTT_{\text{red}} = 0.15$  to 0.2 still have a positive effect on compliance even for high sacrifice levels. This means that only significant global gains were considered worthy by users when the sacrifice was high. The threshold here seems to be around 15% of total traveled time reduction.

For the second sub-question on emission reduction, Fig. 9(a) presents the compliance in session 4 (solid line) as calculated with the social path (P3) choice frequency in session 4 (dashed line) and the observed choice frequency of P3 in session 3 (dotted line), see also Eq. 5. Here only three values of choice frequency are calculated for three intervals of travel time sacrifice, due to data sampling problems in obtaining reliable estimations of choice frequency. Notable differences from the previous sub-question case can be pointed out. As mentioned earlier, compliance is much lower in session 4 in comparison to session 2, due to the mode preference for public transport observed in session 3. Likewise, and as expected, compliance decreases with the increase of sacrifice, but the decrease is much slower when compared to session 2. Hence, the

Table 3  
Estimated coefficients of the Mixed Logit model.

Attribute	Mean value $\bar{\beta}$	Standard dev. $\sigma(\beta)$
Travel time sacrifice		
Constant	-9.87 (0.365) ***	4.75 (0.198) ***
With TTT red. information	5.47 (0.495) ***	4.21 (0.409) ***
With PT mode	4.46 (0.415) ***	2.63 (0.222) ***
With $\text{CO}_2$ emission red. Information	-3.24 (0.408) ***	2.63 (0.301) ***
TTT reduction	14.1 (0.831) ***	5.66 (0.478) ***
Public transport (PT) alternative	4.1 (0.218) ***	2.99 (0.121) ***
$\text{CO}_2$ emission relative reduction	4.04 (0.324) ***	2.06 (0.228) ***

The coefficients are displayed as follows: mean estimator (standard dev.) Signif. codes for p-value: \*\*\* (< 0.001); \*\* (< 0.01); \* (< 0.05); . (< 0.1).

definition of a threshold is almost impossible in this case. Putting aside the effect of mode preference, this suggests a clear difference in the perception of the social path between the two sub-questions. Whereas the effect of the advice message is immediate but rapidly decreases with travel time sacrifice in session 2, the  $\text{CO}_2$  emission information seems less sensitive to the level of sacrifice. This perception difference is further confirmed when looking at Fig. 9(b), which depicts the evolution of compliance in session 4 for various levels of  $\text{CO}_2$  emission reduction (compared to the emission of P1). Unlike session 2, the effect of the social benefit value is very clear in session 4. A low relative reduction of emission has no effect ( $\text{CO}_2$  reduction of 0.3), whereas a larger emission reduction (0.6 to 0.9) leads to an obvious increase of compliance.

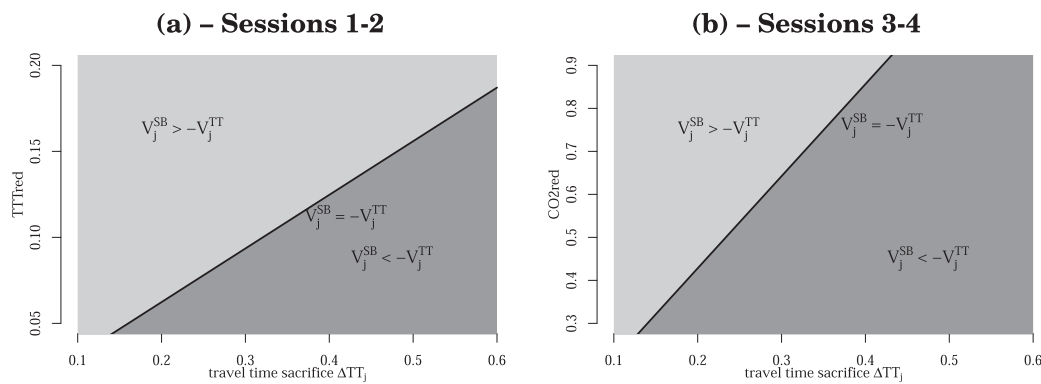
#### 4.2. Route choice model

In order to further investigate the experimental results, a panel data Mixed Logit model was fitted to the choice data. The model was estimated with the GMNL package (Sarrias and Daziano, 2017) for the R-project. In this framework, the utility function  $U_{ij}$  of taking path  $j$  for user  $i$  is expressed as follows:

$$U_{ij} = V_{ij} + \epsilon_{ij} = \beta_i \cdot x_j + \epsilon_{ij} \tag{6}$$

where  $V_{ij}$  is the deterministic part of the utility,  $\beta_i$  is the vector of coefficients for user  $i$ ,  $x_j$  is the vector of attributes for path  $j$ , and the  $\epsilon_{ij}$  are independent and identically distributed zero-mean residual terms (encompassing the effect of all unobserved factors). The estimated mean and standard deviation of the coefficients are presented in Table 3. The model estimation used simulations with 1000 draws. It was run several times and 1000 draws proved to be sufficient to ensure good stability in the parameter estimators.

Table 3 groups coefficients that are all very significant to explain users' choices. In the Mixed Logit model, each coefficient  $\beta$  is actually assumed to come from a (normal) distribution representative of the



**Fig. 10.** Competition between the effect of the travel time sacrifice and the social benefit in the utility function for choosing the social path ( $j = \text{SoP}$ ). (a) Social benefit values counterbalancing the travel time sacrifice for the first sub-question (sessions 1–2), and (b) for the second sub-question (sessions 3–4).

diversity between users. Each distribution is thus characterized by its mean value  $\bar{\beta}$  and standard deviation  $\sigma(\beta)$ . The coefficient  $\beta_{TT,i}$  associated with the travel time sacrifice  $\Delta TT_j$  is decomposed into four terms: a constant  $\beta_{TT,i}^0$  common to all sessions, a term  $\beta_{TT,i}^{TTT}$  only occurring when the social path (P2 or P3) is proposed in session 2, a term  $\beta_{TT,i}^{PT}$  only occurring when the public transport path (P3) is introduced in sessions 3 and 4, and a term  $\beta_{TT,i}^{CO2}$  only occurring when the social path (P3) is suggested in session 4. Thus we have:  $\beta_{TT,i} = \beta_{TT,i}^0 + \beta_{TT,i}^{TTT} \delta^{TTT} + \beta_{TT,i}^{PT} \delta^{PT} + \beta_{TT,i}^{CO2} \delta^{CO2}$ , where  $\delta^{TTT} = 1$  if an advice message is given (session 2) and 0 otherwise,  $\delta^{PT} = 1$  if a public transport option is proposed (sessions 3 and 4) and 0 otherwise, and  $\delta^{CO2} = 1$  if the emission information is provided (session 4) and 0 otherwise. The purpose of this decomposition is to identify the effect of these elements (SoP recommendation and PT mode) on the perception of travel time sacrifice. As expected, we can see that the constant part has a negative impact on users' utility. However, it is interesting to observe how this impact is reduced due to the presence of the recommendation message in session 2. This is also the case of the public transport mode in session 3, but surprisingly its effect alone is more effective than the combined effect of public transport and CO<sub>2</sub> emission information together in session 4. The coefficient of the TTT reduction is associated with the value of  $\Delta TTT_{red}$  for the social path in session 2. Its high value suggests a considerable positive effect on utility, which corroborates our observations in the previous section. The coefficient of the public transport mode is associated with a Boolean indicating whether the path is PT mode or not. Again, as seen before, its positive impact relates to the mode preference of users. Finally, the coefficient associated with the CO<sub>2</sub> emission reduction also has a positive effect on utility, although lower than that of the TTT reduction, as observed earlier.

Using relative differences for travel time and CO<sub>2</sub> emission instead of absolute values allows normalizing these quantities and mixing all the choice situations in the same analysis. This is particularly useful to

compare path choices on different OD pairs, with possibly very different travel times. With normalized values every path choice situation is given the same weight in the analysis (the same method can be found in e.g., Gonzalez Ramirez et al., 2019). Moreover, this allows the direct comparison between all coefficients as they are all associated with values in [0, 1]. The (normalized) departure time and the OD pair (indicated with a Boolean) implied in path choices were also included in the model, but were found to be very insignificant, thus not presented here.

To go further, these results allow calculating the compensation values of social benefit required to counterbalance the negative effect of travel time sacrifice. Let us write  $V_j^{TT}$ , which is the part of deterministic utility corresponding to the travel time sacrifice, and  $V_j^{SB}$ , that associated with the social benefit. Here we use the mean values of coefficients from Table 3, which removes the user dependency in the utility. For the first sub-question on congestion alleviation, in session 2 we have  $V_j^{TT} = (-9.87 + 5.47) \Delta TT_j$  and  $V_j^{SB} = 14.1 SB_j$ , see Eq. 2 for the definition of  $SB_j$ . For the second sub-question on emission reduction, in session 4 we have  $V_j^{TT} = (-9.87 + 4.46 - 3.24) \Delta TT_j$  and  $V_j^{SB} = 4.04 SB_j$ . When comparing each utility term, the counterbalance of social benefit starts when  $V_j^{SB} \geq -V_j^{TT}$ . In the Logit model, this also means that the elasticity of choice regarding the variable  $SB_j$  is greater than that regarding the variable  $\Delta TT_j$ . The values of social benefit and sacrifice satisfying with this inequality are shown in Fig. 10(a) and (b) for the first and second sub-questions, respectively. As observed earlier, the recommendation on congestion alleviation allows a stronger counterbalance of travel time sacrifice, in comparison to the CO<sub>2</sub> emission information, at least within the range of  $\Delta TT_j$  and  $SB_j$  in our experiment design.

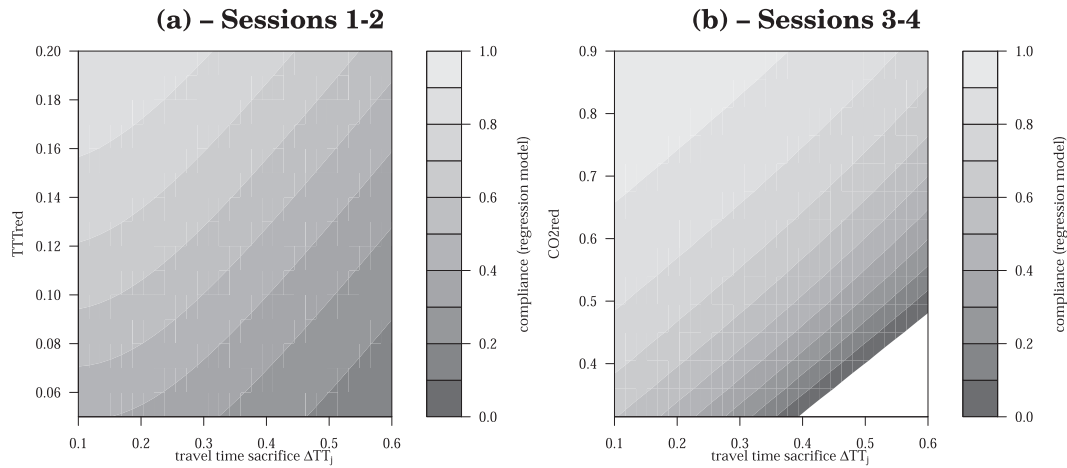
#### 4.2.1. Separate route choice model for car and PT sessions

The estimates for the separate models are presented in Table 4, where it can be seen that, except for the travel time constant in sessions 3–4 (PT), the results (signs and magnitude) are in agreement with those

**Table 4**  
Estimated coefficients of the Mixed Logit regression model for sessions 1–2 and 3–4.

Attribute	Full model		Sessions 1–2 (car)		Sessions 3–4 (PT)	
	Mean $\bar{\beta}$	S.D. $\sigma(\beta)$	Mean $\bar{\beta}$	S.D. $\sigma(\beta)$	Mean $\bar{\beta}$	S.D. $\sigma(\beta)$
Travel time sacrifice						
Constant	-9.87***	4.75***	-10.80***	6.33***	-15.38***	5.25***
With TTT info.	5.47***	4.21***	6.29***	5.18***	-	-
With PT mode	4.46***	2.63***	-	-	10.23***	1.54***
With CO <sub>2</sub> info.	-3.24***	2.63***	-	-	-2.39***	2.14***
TTT reduction	14.1***	5.66***	16.23***	8.55***	-	-
Public transport (PT)	4.1***	2.99***	-	-	3.65***	4.05***
CO <sub>2</sub> emission reduction	4.04***	2.06***	-	-	3.43***	1.99***

The coefficients are displayed as follows: mean estimator (standard dev.) Signif. codes for p-value: \*\*\* (< 0.001); \*\* (< 0.01); \* (< 0.05); (< 0.1).



**Fig. 11.** Compliance for the two sub-questions as the result of the Mixed Logit model fitted for the simplified choice problem. (a) Compliance for the social path ( $j = \text{SoP}$ ) as a function of travel time sacrifice and the value of social benefit for the first sub-question (sessions 1–2), and (b) for the second sub-question (sessions 3–4).

of the full model presented above. The difference in the travel time constant between the full model and the model for sessions 3 and 4 is explained by the presence of two car and one PT alternatives. To be more precise, for a non PT alternative  $j$  we have that the travel time sacrifice is given by  $V_j^{TT,S3-4} = -15.38 < -9.87 = V_j^{TT,full} \approx V_j^{TT,S1-2}$ , i.e., an increment in travel time will make the rest of the car alternatives much less interesting when there is a PT alternative available. However, when the alternative  $j$  is PT (no CO<sub>2</sub> information), then the travel time sacrifice, given by  $V_j^{TT,S3-4} = -15.38 + 10.23 = -5.15$  and  $V_j^{TT,full} = -9.87 + 4.46 = -5.41$ , are similar. These results suggest that when a PT alternative is available, participants tend to evaluate the fastest car alternative vs the PT alternative, discarding the slower car alternatives, and when no PT alternative is available, participants evaluate the trips in terms of travel time gains. Now, comparing the full model against the model for sessions 1 and 2, we have similar travel time sacrifice for the social path:  $V_j^{TT,S1-2} = -10.80 + 6.29 = -4.5$  and  $V_j^{TT,full} = -9.87 + 5.47 = -4.40$ , although in the model for sessions 1 and 2 the travel time reduction ( $V_j^{SB}$ ) has a slightly higher weight. In general, the preferences of individuals across the three models are consistent, however, the full model captures better the importance of the travel time, as it is estimated considering problems with and without a PT alternative.

#### 4.3. Problem simplification and compliance analysis

The use of a Mixed Logit model can provide further understanding of participants’ compliance if several assumptions are made regarding the experiment. These assumptions come with an important observation on participants’ choices in sessions 2 and 4: Because of the very low proportion of choices in favor of the path which is neither the shortest nor the social one (see Fig. 3), we are now going to ignore it. This allows simplifying the choice situation into a two-path problem, where users have to decide between a short selfish alternative or a long social one. Henceforth, let us redefine P1 as the shortest path and P2 as the social path. This simplification removes the dependency of the observed factors on the third path in the experiment. By using the closed form of the Logit model, we can express the probability  $p_{i,2}$  for user  $i$  of taking the social path P2 as follows:

$$p_{i,2} = \frac{e^{V_{i,2}}}{e^{V_{i,1}} + e^{V_{i,2}}} = \frac{1}{1 + e^{V_{i,1} - V_{i,2}}} \quad (7)$$

With the model estimated in the previous section, the deterministic utility  $V_{i,2}$  of the social path P2 is given by:  $V_{i,2} = \beta_{TT,i} \cdot \Delta TT_2 + \beta_{SB,i} \cdot SB_2 + \beta_{PT,i} \cdot \delta_2^{PT}$ , where  $\delta_2^{PT}$  equals 1 if P2 is a public transport

alternative and 0 otherwise. The deterministic utility  $V_{i,1}$  of the shortest path P1 is null because  $\Delta TT_1, SB_1$  and  $\delta_1^{PT}$  are null by definition. If we consider only the mean values of the coefficients, we obtain the average probability  $p_2$  of taking the social path P2 as:

$$p_2 = \frac{1}{1 + \exp(-\beta_{TT} \cdot \Delta TT_2 - \beta_{SB} \cdot SB_2 - \beta_{PT} \cdot \delta_2^{PT})} \quad (8)$$

This closed form has the considerable advantage of expressing the probability of choosing P2 as a function of its sacrifice  $\Delta TT_2$  and social benefit  $SB_2$ . This is the result of our simplification into a two-path problem, so that this expression does not depend on the observed sacrifice and benefit on a third path. Note that a similar function shape was used in Oh et al. (2001) to define the probability of choosing the recommended path depending on its travel time savings (no notion of social benefit was included). Hence, using the mean coefficients estimated with the Mixed Logit model (see Table 3) allows us to give a formula of the compliance function of the sacrifice and social benefit:

$$\kappa = \frac{p_2 - p_2^0}{1 - p_2^0} \quad (9)$$

where  $p_2$  is the probability of taking the social path when the recommendation or information is given, and  $p_2^0$  is the probability of taking the same path when not labeled as a social path, i.e. when no recommendation or information is given (control test). For the first sub-question on congestion alleviation, we use  $(\beta_{TT}; \beta_{SB}; \beta_{PT}) = (-9.87; 0; 0)$  from session 1 to calculate  $p_2^0$  and  $(\beta_{TT}; \beta_{SB}; \beta_{PT}) = (-9.87 + 5.47; 14.1; 0)$  from session 2 to calculate  $p_2$ . For the second sub-question on emission reduction, we use  $(\beta_{TT}; \beta_{SB}; \beta_{PT}) = (-9.87 + 4.46; 0; 4.1)$  from session 3 to calculate  $p_2^0$  and  $(\beta_{TT}; \beta_{SB}; \beta_{PT}) = (-9.87 + 4.46 - 3.24; 4.04; 4.1)$  from session 4 to calculate  $p_2$ .

The resulting compliance levels in both sub-questions are plotted in Fig. 11(a) and (b) respectively. The lines defined by the gray shaded areas correspond to iso-compliance (same level of compliance). In both figures, a similar pattern is found: the higher the sacrifice, the higher the social benefit must be to achieve the same compliance. Interestingly, the compliance patterns in both figures appear very regular. Moreover, we again observe the differences between the two sub-questions: for a given sacrifice, a higher benefit is required to reach the same compliance in the case of emission reduction compared to congestion alleviation. In Fig. 11(b), the region with a low benefit and a high sacrifice is undefined (the model gives a negative compliance). This is the limit of the Mixed Logit model estimation which is probably not valid for this region, due to fewer observations. Although the result of a simplification of the initial experiment situation, these two plots

are appealing as they provide a general picture of the expected evolution of compliance.

## 5. Conclusion

In this paper, we analyzed a stated preference survey to understand and measure the competition between selfish goals and social objectives when faced with a path choice situation with recommendation. Our stated preference study consisted of a computer application that automatically generates multiple and various path choice situations based on a real city map. Every respondent was asked to select his/her preferred path in a succession of situations. Around 17,200 choice observations were collected with 133 participants from different social backgrounds. Our experiment was split into two sub-questions targeting two social objectives: (i) how do travelers react to the recommendation of a social path which is said to reduce traffic congestion? and (ii) how do travelers react to new information on CO<sub>2</sub> emissions associated with each path? We used the notion of compliance to measure travelers' reactions, defined as the number of users who moved to the social path over the number of users who would be traveling on other paths if no recommendation were made. This new definition has the advantage of accounting for the proportion of users who naturally prefer the social path for other reasons, whatever the recommendation. Compliance, as we consider it, is thus a measure of the recommendation efficiency.

The results showed different reactions to these two objectives. For the first sub-question, we observed a high impact of the recommendation when the sacrifice was low, which may be explained by a satisficing behavior (Simon, 1955). Compliance then quickly drops as the sacrifice increases. The value of the congestion reduction in the advice message was found to be significant in moving travelers to the social path, albeit quite subtly. However, for the second sub-question, the role of the emission reduction value was clearer: a significant reduction was required to show a significant impact on compliance. It was surprisingly less sensitive to the increase in sacrifice. Notable differences between the two cases also played a role: the social path was a public transport alternative and the recommendation was implicit by showing lower emissions for this path. In our participant set, a natural preference for public transport mode explained the lesser effect of the emission information. Although the general trends of traveler behavior were expected and already pinpointed in the literature, the use of a Mixed Logit model and a simplification into a two-path problem allowed proposing a quantification of compliance regarding the levels of sacrifice and social benefit.

This study must still be confirmed by other findings from real situations,

as the stated intentions of travelers are always likely to be more optimistic than the revealed choices of the same travelers. We can thus expect less compliance in reality. Nevertheless, our findings could contribute to the design of route guidance policies to set thresholds of sacrifice and benefits. For instance, it can help estimating a maximum travel time sacrifice and a minimum expected benefit to ensure a given level of compliance, critical for the efficiency of the route guidance system.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Contribution statement

The authors confirm contributions to the paper as follows: Study conception and design: G. Mariotte, L. Leclercq; Computer survey preparation and design: G. Mariotte, J. Krug, C. Bécarie; Data collection: G. Mariotte, L. Leclercq, H. Gonzalez Ramirez, J. Krug, C. Bécarie; Analysis and interpretation of results: G. Mariotte, L. Leclercq, H. Gonzalez Ramirez; Supervision: L. Leclercq; Draft manuscript preparation: G. Mariotte; Manuscript revision: H. Gonzalez Ramirez, G. Mariotte. All authors reviewed the results and approved the final version of the manuscript.

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## Appendix A. Extract of Origin–Destination pairs with their paths used in the experiment

Fig. 12.

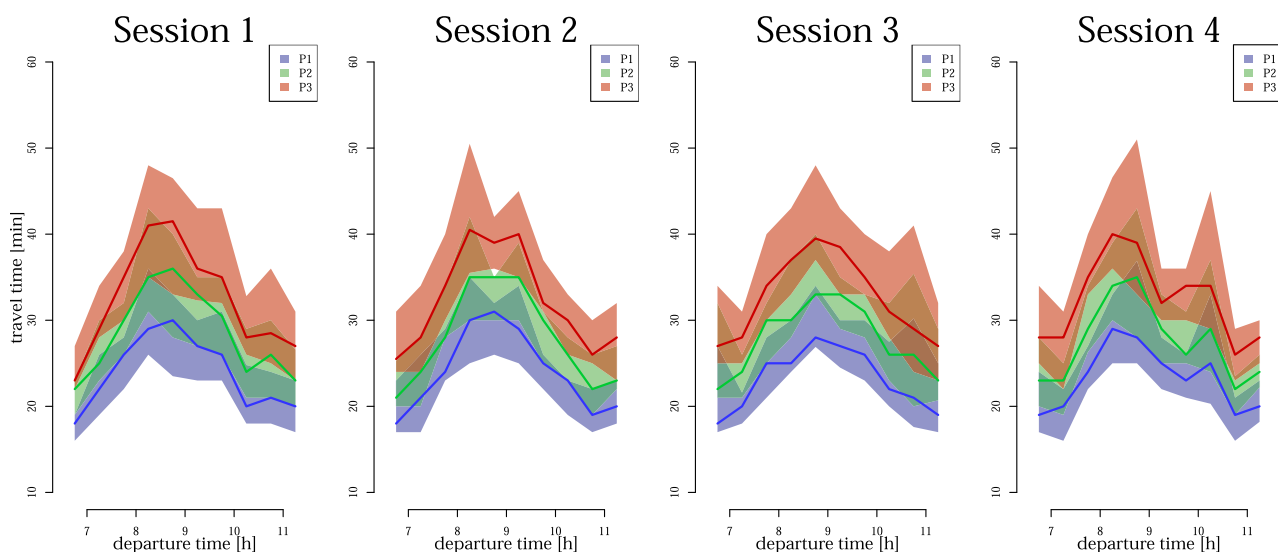


Fig. 12. Extract of 4 maps of OD couples with paths representative of the 14 maps used in the experiment.

Appendix B. Distributions of path attributes in the experiment

Figs. 13–16.

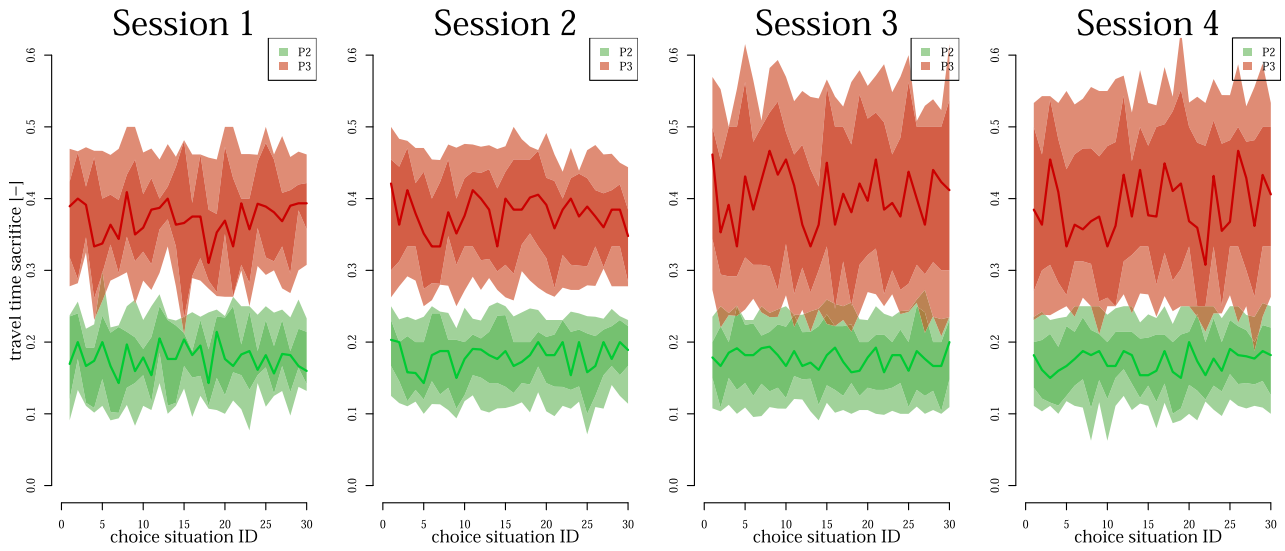


Fig. 13. Values of travel time used in the experiment for the 3 paths of a given OD pair vs the departure time picked. The variability corresponds to the different values shown for the different participants (median with 3rd–7th deciles).

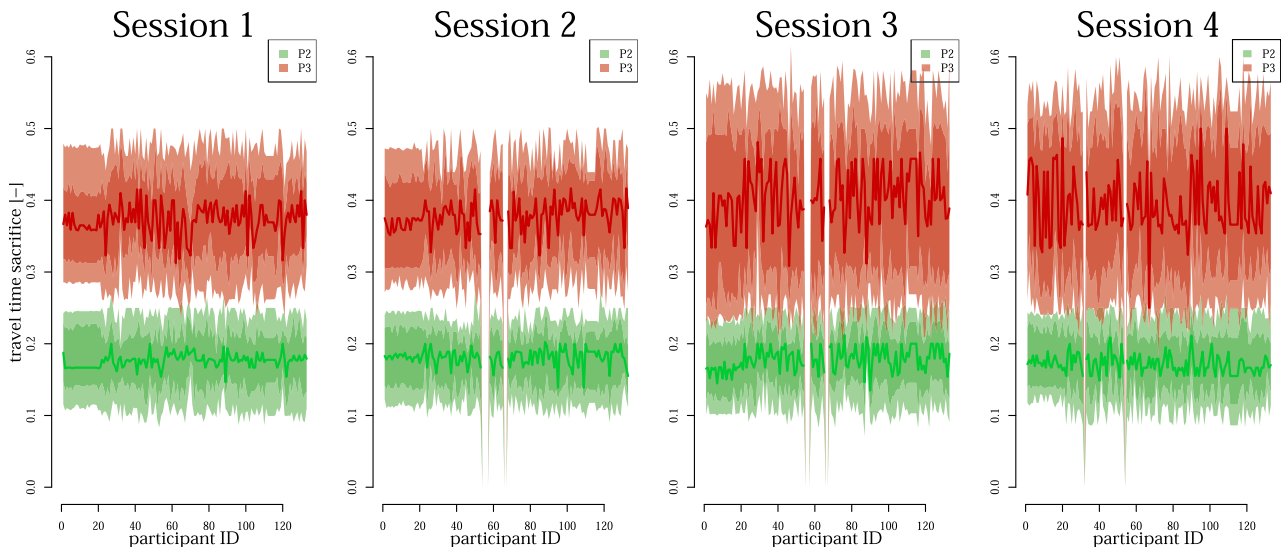


Fig. 14. Values of travel time sacrifice (relative increase regarding P1 travel time) used in the experiment for P2 and P3 of all OD pairs vs the first 30 choice situations shown to participants. The variability corresponds to the different values shown for the different participants (median with 1st–3rd–7th–9th deciles).

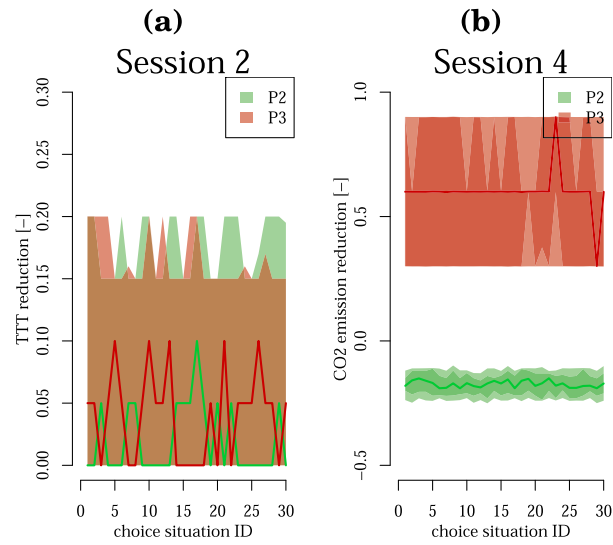


Fig. 15. Values of travel time sacrifice (relative increase regarding P1 travel time) used in the experiment for P2 and P3 of all OD pairs vs the participant list. The variability corresponds to the different values shown for the different departure times picked (median with 1st–3rd–7th–9th deciles).

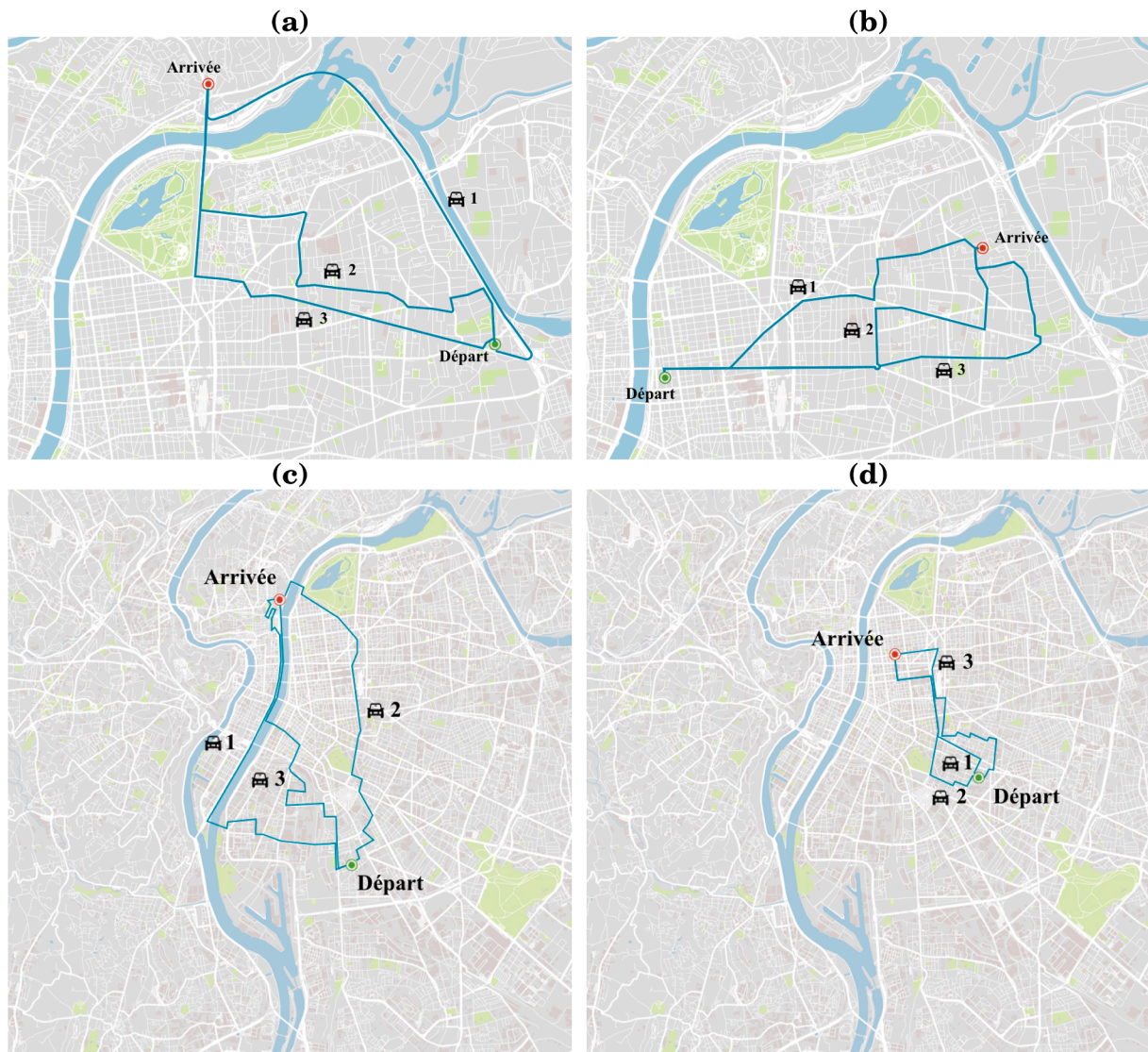


Fig. 16. (a) Values of TTT reduction used in the experiment for P2 and P3 of all OD pairs vs the first 30 choice situations shown to participants in session 2 (by default, a value of 0 is used when the path is not defined as the social path). (b) Values of CO<sub>2</sub> emission reduction used in the experiment for P2 and P3 of all OD pairs vs the first 30 choice situations shown to participants in session 4. The variability corresponds to the different values shown for the different participants (median with 3rd–7th deciles).

## Appendix C. Evolution of the choice of participants as they participated in more tasks

Fig. 17.

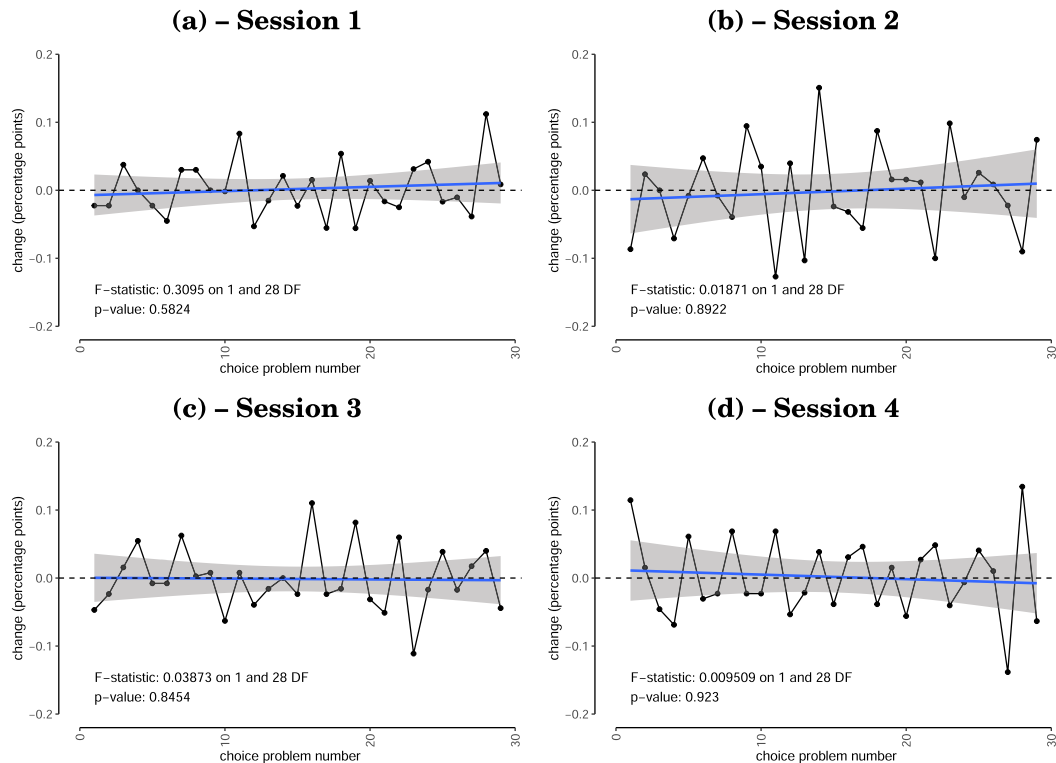


Fig. 17. Choice evolution. The change in the percentage of choices for the shortest route (path 1) as a function of the choice number. A regression analysis (blue) shows that there is not enough statistical evidence to support that there is a trend in the responses of participants.

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