

## Article

# Development and Assessment of a Carpooling Applied System: Perspective of Users from Public-Education Sector

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**Abstract:** The heavy reliance on private cars is linked not only to harmful environmental impacts, such as gas emissions and global warming, but also to other issues like traffic congestion, road infrastructure maintenance, and the limited availability of parking spaces—significant concerns in many cities. To address these challenges, carpooling has been shown to be an effective solution, as it directly reduces emissions, alleviates congestion, and mitigates the environmental effects of transportation. The aim of this research is to enhance the understanding of carpooling in our society. To achieve this, a carpooling initiative among teachers for their commuting journeys was developed and implemented, followed by an evaluation of the system by a panel of experts. The results showed a 31.9% reduction in the number of cars on the road among participants, with a total of 109,080 km saved based on the reduced number of vehicles. The primary motivation for participants to adopt carpooling was fuel savings, while the reduction of physical fatigue from driving was identified as the second most important factor. Although some barriers to participation were identified, their impact was generally lower than that of the perceived benefits. These findings suggest that carpooling programs should focus on optimizing matching conditions and addressing individual concerns to promote wider adoption.

**Keywords:** sustainable mobility; carpooling; smart mobility; sharing economy; public-sector



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## 1. Introduction

Human transportation is a key aspect of our society. The sustainable development of transportation systems has been recognized as a crucial requirement for meeting the objectives of the United Nations 2030 Agenda for Sustainable Development, particularly in achieving the reduction of greenhouse gas emissions outlined in Goal 13 on climate action [1]. In most of developed countries, private vehicles are the preferred choice for daily travel [2], and consequently, private transportation has become a major contributor to global warming [3]. This intensive use of private cars is associated not only with negative environmental effects—gas emissions and global warming—other problems such as traffic congestion, road infrastructure maintenance, or the availability of parking facilities are causes of concern in many cities.

In order to address this variety of effects, pooling has been shown to be an effective strategy, as it directly reduces emissions, congestion, and environmental impacts of human mobility [4,5]. Just to give a relevant example, only in San Francisco 1.7–3.5 million liters of fuel are estimated to be saved each year through the use of carpooling [6]. Carpoolers can also benefit from the use of high-occupancy vehicles (HOV) lanes to avoid bottlenecks [7].

Carpooling and van pooling are not new practices [8]. They have a long history in countries such as the United States, where commuter employers often agree to travel

grouped into a car to complete their common trip to or from the workplace. In other countries, such as France, Italy and Spain, it has also been demonstrated that employer initiatives and promotion possibilities can increase the adoption rate of carpooling [9–11].

The Sustainability of carpooling models and practices has been highlighted by several authors [12–14]. Some studies detected that value beliefs, and pro environmental behavior were found relevant to select carpooling before to other transportation alternatives [15]. Other research suggested that new platforms and apps can make carpooling more attractive than other ride sharing options [16]. Additionally, other previous research stated that sharing options can be considered complementary because all of them contributes to reduce environmental impact [17].

Several variables influence the performance of carpooling systems; they can be classified into four main groups: psychosocial, situational, sociodemographic, and third-part interventions factors [18]. Addressing this complexity provides fertile ground for research. In recent years, communications technologies have enabled and promoted shared mobility services, offering new alternatives to solo- drivers and increasing the car occupancy while maintaining the advantages of private vehicles. Consequently, more dynamic and flexible carpooling models and systems are now possible, e.g., with the integration of smart devices and social networks [19,20]. Furthermore, current technologies make possible the increase of matching rates. This is an important aspect, since in previous research high matching rates have been identified as a key factor to maintain the adoption of carpooling practice [21–24].

However, in spite of their potential benefits, new pooling alternatives are often underutilized due to different reasons, such as user adoption barriers, low matching rates or inefficient (suboptimal) systems [25]. Therefore, it is of great interest to provide insights of the recent research addressing the cited carpooling issues in order to promote better carpooling alternatives for sustainable mobility.

In this sense, sustainability in transportation, aligns closely with the principles of the sharing economy [21]. Also, the implementation of smart mobility solutions such as carpooling in the context of smart cities requires significant collaboration with the public sector, which often plays a key role in the development of infrastructure, regulatory frameworks, and incentives for technology adoption [26].

The current article is aimed at providing a better understanding of carpooling applied in our society. First at all, a carpooling experience among teachers in their commuting journeys, was designed and performed, and secondly the experience was evaluated through an expert panel. The structure of the document is as follows. In the first section the topic and the pursued goals were introduced. In the second section the methodology of the research was described in detail. In the third section the results were discussed. The paper concludes by highlighting the most relevant findings and suggesting directions for future research.

## 2. Methodologies

Two different methodologies were used in current research. Both are detailed in the following subsections.

### 2.1. Development of the Carpooling Experience

The first methodology was necessary to design and carry out the carpooling experience. Carpooling experience was based on a previous research related. The proposed system has been carried out considering the peculiarities of the education sector and following majority of the guidelines proposed in a previous research [27]. Due to the confidential issues related with the use of a professionals database to manage teachers personal information, the system was carried out based in the information provided by potential carpoolers. Teachers were informed about the experience in the initial general meeting of the academic year 2022–2023. Everyone who expressed their desire to participate was included in a list. Once

they were included, they were asked to fill a brief form with their personal information such as: Age, Gender, Trip mileages, Zip Codes, Length as a driver, etc.

A carpooler coordinator was assigned in order to process the information needed. Figure 1 details the procedure to collect and process the information necessary to carry out carpooling practices systematically.

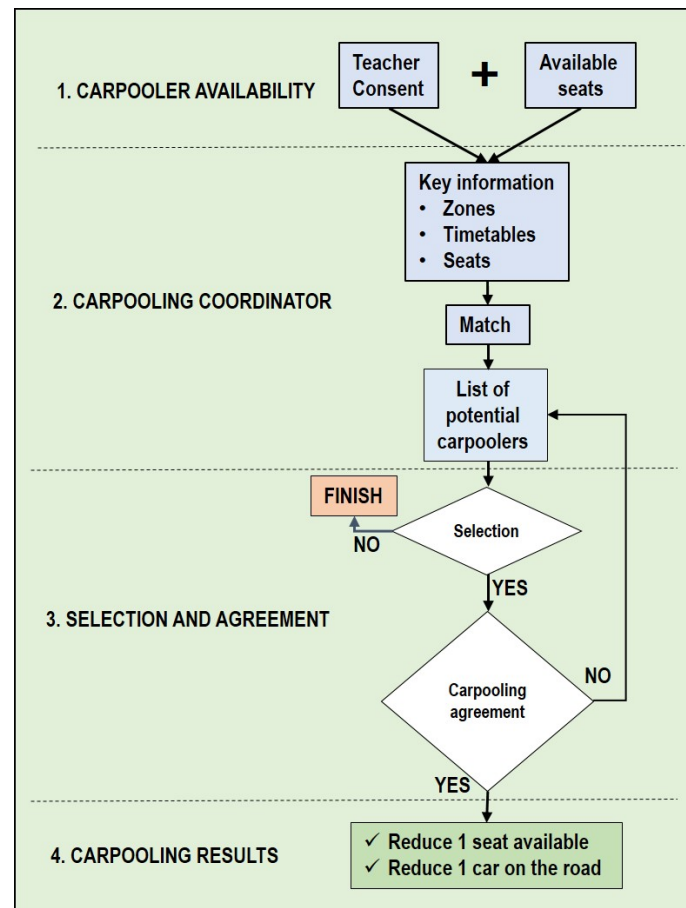


Figure 1. Carpooling proposal flowchart. Adapted from Rey et al. [27].

Then, the system is executed according to the following steps:

1. **Carpooler availability:** In the first step, teachers interested in the carpooling system communicate their interest to the carpooler coordinator. They should also indicate the number of available seats for possible carpool users.
2. **Carpooling coordinator:** A member of the Carpooling group was responsible as a coordinator to collect the following key information.
  - Zone of departure and arrival (Zip codes)
  - Available seats.
  - Working timetables (Entrance and exit)

According to the match criteria, coordinator will search for matches in timetables and zip codes, and based on the matches provided a list of potential carpoolers. They were ranked by matching level.

3. **Selection and agreement:** Based on the list provided each user agreed or not on the option to carpool.
4. **Carpooling results:** If they agree to carpool, then the list was updated. The driver will reduce one seat available, and the passenger will eliminate their car from the available cars for that trip .

According to the steps described, the carpooling experience was carried out, and their results were detailed and discussed in Section 3.

## 2.2. Evaluation of the Experience Through an Expert Panel

The second methodology was used to evaluate the experience. Once the carpooling experience was performed, a qualitative method was applied to analyze the experience' results. In order to achieve this objective, a single-round Delphi Method, known as the staticized group technique was carried out. The Delphi Method is well-documented in literature as an effective means of group-based judgment and decision-making [28]. Previous studies using the Delphi approach describe it as a systematic and interactive research technique that gathers the judgments of a panel of independent experts on a specific topic [29]. Experts are selected according to predefined criteria and participate in two or more rounds of structured surveys. After each round, participants receive an anonymized summary of the results, allowing them to review the anonymous opinions of their peers and revise their inputs in subsequent rounds. This iterative process aims to reduce result variability and achieve a consensus on the most accurate value. The process concludes either when consensus is reached or after a predetermined number of rounds.

The staticized group technique resembles the Delphi Method but lacks feedback and additional rounds. The staticized groups methodology has been applied in various fields such as healthcare [30] and sustainability [31]. There are differing opinions regarding the accuracy of consensus achieved through the Delphi Method. Some researchers found no significant difference in accuracy between the Delphi and staticized group approaches, while others advocate for the staticized group technique, arguing that it avoids guiding participants towards a consensus on a potentially suboptimal value. This rationale underpins the use of staticized groups in the current study.

Although generalizing results from a small expert panel to a larger population lacks statistical significance, one of the main strengths of the staticized group methodology is leveraging the expertise of specialists in a specific field. The selected experts possess knowledge that exceeds that of a representative sample, thus their insights provide valuable benefits for both research and practical applications.

### 2.2.1. Expert Selection

In staticized groups methodology, expert selection is a key factor. Previous studies were developed with a number of experts among 8 and 16 panelists and a minimum of 8 was suggested. In current research the authors incorporate 14 panelists from the carpooling experience. Half of the selected experts were women (Experts 1 to 6) and the other half were men (Experts 7 to 12). The requirement of the experts was defined in the literature [29] as the most important facet of the method. A flexible point system adapted to the specific aim of our research is summarized in Table 1. According to that, the results obtained by each panelist in the flexible point system are detailed in Table 2.

**Table 1.** Achievements included in the Flexible point system for panelist selection. Adapted from Rey et al. 2022 [31].

Achievements or Experience	Code	Points
Carpoolers before the current research	A1	3
Year of experience as a carpooler	A2	2
Commuting between different cities	A3	3

**Table 2.** Achievements included in the Flexible Point System for panelist selection. Adapted from Rey et al. 2022 [31].

Panelist	A1	A2	A3	Total
1	3	24	3	30
2	3	22	3	28
3	0	40	3	43
4	3	30	3	36
5	3	28	3	34
6	0	32	3	35
7	3	20	0	23
8	3	12	0	15
9	0	18	3	21
10	0	20	3	23
11	3	40	3	46
12	3	24	0	27
13	0	36	3	39
14	3	20	3	26
AVG	2	26	2	30
MED	3	24	3	29
DESV	1.49	8.50	1.28	8.83

Regarding the personal conditions of the participants, the panel of experts was finally made up of 7 women and 7 men. Once a year, a high percentage of them are relocated to a different workplace; the distance that they must commute varies. Although their mobility patterns are important to design sustainable transportation alternatives, official data about it are not published.

### 2.2.2. Questionnaire Design

The items selected for the questionnaire were adapted from a previous research [31] based on scientific literature. Carpooling factors were classified as incentives (Table 3) or barriers (Table 4). They were evaluated by panelist according to the carpooling experience developed.

**Table 3.** Incentives perceived in the carpooling experience adapted from Rey et al. 2022 [31].

Category	Incentives	Authors	Code
Vehicle	Fuel-saving	[6,32–34]	I1
Personal	Reduce driving physical fatigue	[33,35,36]	I2
	Reduce driving mental fatigue	[33,35,36]	I3
	Rest during the displacement	[33,35,36]	I4
Social	Support from coworkers in the same situation	[35,37]	I5
	Improves relations between coworkers	[38]	I6
	Socialize out of the worksite	[39]	I7
Environmental	Reduce emissions	[25,40,41]	I8

**Table 4.** Barriers detected in the carpooling experience adapted from Rey et al. 2022 [31].

Category	Barriers	Authors	Code
Vehicle	Low fuel-saving	[39,42]	B1
Time	Spending time waiting for coworkers	[38,42,43]	B2
	Earlier start of the journey	[44]	B3
Personal	Less Independence	[33,35]	B4
	Different genders of coworkers	[11,15,45]	B5
Social	Social awkwardness	[46,47]	B6
	Extending work problems to the car	[48,49]	B7
	Low-match of coworkers' timetables	[50]	B8

A Likert scale was presented to the experts for evaluating the items. It is a psychometric instrument consisting of a series of statements related to the study's hypothesis [51].

An online survey was employed to gather participants' feedback. To minimize bias and enhance the research quality, the following strategies were implemented: The questions were randomized for each participant to mitigate the contrast and primacy effects, and the anonymity of all panel members was guaranteed.

The staticized group methodology did not require reaching a consensus; instead, variance and standard deviations were calculated to compare the outcomes with those obtained through the Delphi method, which involved additional rounds of feedback. The reliability of the questionnaire was assessed using Cronbach's alpha coefficients [52].

### 3. Results and Discussion

#### 3.1. Carpooling Experience

A sample of 56 participants complete the carpooling experience during an academic year (9 months). The most relevant characteristic of the participants are summarized in Table 5.

**Table 5.** Drivers' personal profile.

Drivers' Personal Profile	Average
Length of driving license (years)	10.9
Annual mileage (km)	13,839
Mileage of most frequent journey (km)	71.5
Age	40.3
Children	1.7

Only fossil fuel cars with a human driver were possible to study, because any participant own electric or autonomous car. They were classified according to 9 different groups based on their personal circumstances such as workplace location and timetables. The groups are described in the following Table 6. The first group is composed by teachers who do not want to share their car, then numbers of cars on the road can not be reduced in this group. In the second group, their members are willing to carpool and match in their zip codes (home and workplace) and timetables (In and Out). In groups three and four they share same timetables but their zips are no equals both. In groups 5 and 6 they share zip codes but their timetables are not the same. In group 7, zips and and time table are not the same but they are close. In group 8 there are not matches, and finally in group 9 they are able to reach workplace without a car.

**Table 6.** Characterization of Group of carpoolers.

Group	Carpooler	Home Zip	Work Zip	Time Match
1	NO	-	-	-
2	YES	EQUAL	EQUAL	IN&OUT
3	YES	NEAR	EQUAL	IN&OUT
4	YES	EQUAL	NEAR	IN&OUT
5	YES	EQUAL	EQUAL	CLOSE IN
6	YES	EQUAL	EQUAL	CLOSE OUT
7	YES	NEAR	NEAR	CLOSE IN&OUT
8	YES	NO MATCH	NO MATCH	-
9	NO	-	-	-

Results were described in Table 7. A reduction of 31.9% of the initial number of cars was achieved among the participants. This result is little higher compared with previous results from experiences as CIVITAS project 30% [9]. This project was focused on a carpooling system for students and staff at the Krakow University of Technology.

**Table 7.** Cars reduction and CO<sub>2</sub> saved during one academic year.

Group	% of Cars Reduced	km Saved/Year	CO <sub>2</sub> kg Saved/Year
Group 1	0.0	0	0
Group 2	60.0	22,680	3402
Group 3	50.0	17,280	2592
Group 4	66.7	14,760	2214
Group 5	60.0	37,800	5670
Group 6	0.0	0	0
Group 7	50.0	16,560	2484
Group 8	0.0	0	0
Total	31.9	109,080	16,362

It is remarkable that is not possible to reduce the number of cars in a 100%. The highest percentage of reduction possible should be 80%, grouping all solo cars, in pooled cars with 5 passengers. This is only possible were matching rates are optimal. Initial rate of 1 passenger per vehicle was increased to 1.4 passenger per vehicle. This rate is higher than habitual commuting rates cited by previous studies which are around 1.1 and 1.2 [35,53]. A total amount of 109,080 km were saved based on the cars reduced, and their trips in one academic year composed by 180 working days. As a consequence, and considering an average of emission of 150 g of CO<sub>2</sub> per car, a total 16,362 kg of CO<sub>2</sub> were not emitted.

### 3.2. Evaluation of the Experience Through an Expert Panel

In the current section, results provided by panelists based on their perception about carpooling experience detailed in previous section, are described (Table 8) and analyzed. The consistency and reliability of the results was tested calculating Cronbach's Alpha in both group of items. Group of items about incentives obtained Cronbach's Alpha of 0.710, while the group of barriers reached a value 0.678. According to conventional thresholds, results with Cronbach's Alpha values above 0.7 are considered acceptable in terms of internal consistency, while values between 0.6 and 0.7 suggest moderate reliability [52].

Thus, while the results can generally be considered reliable and consistent, there is room for improvement in the items related to barriers, suggesting some heterogeneity in respondents' perceptions of the challenges related to carpooling.

Then results can be considered reliable and consistent [52].

On one hand, main benefits perceived by experts were evaluated in Table 8. Fuel-saving was pointed by experts with highest value (Item I1; AVG = 9.57). The importance of the fuel-saving as an incentive to carpooling has been highlighted by several authors [6,25,34,54,55].

An incentive related with fuel-saving is the reduction of CO<sub>2</sub> emission. Although drivers pointed with high values the emission reduction (Item I8; AVG = 7.93), the importance of cited incentive is lower than fuel-saving. This is motivated because drivers tend to associate fuel-saving with money-saving in a stronger way than emission reduction, although both are associated similarly [49,56]. Then, the reduction of 31.9% of the vehicles achieved in the experience is considered by participants in a fuel-saving incentive.

Fuel savings represent a tangible and immediate economic benefit, which resonates strongly with drivers who tend to prioritize personal financial gains. This reinforces the notion that economic incentives, particularly those tied to fuel costs, serve as key motivators for carpooling adoption. Despite the environmental advantages of carpooling being well-established, the direct economic impact appears to weigh more heavily in individuals' decision-making processes.

Regarding personal variables the reduction of driving physical fatigue scored the second highest value in the group of incentives. This, incentive was pointed by previous researchers as an important reason to adopt carpooling [42,57]. In contrast social variables such as support from coworkers, socialization or improves relation obtained the lowest values. However, all the item were obtained values higher than 7.

**Table 8.** Benefits perceived by experts during their experience. (Cronbach's Alfa = 0.710).

Item	I1	I2	I3	I4	I5	I6	I7	I8
E1	10	9	9	8	7	8	8	8
E2	9	8	8	8	8	7	7	8
E3	10	8	8	8	7	7	8	8
E4	10	9	8	8	7	7	7	7
E5	10	8	9	8	6	6	7	7
E6	9	9	8	7	7	7	8	8
E7	10	7	8	7	6	6	7	7
E8	9	8	7	7	8	8	8	8
E9	9	8	7	7	7	7	6	8
E10	10	8	7	7	8	8	7	9
E11	10	8	8	8	8	8	6	9
E12	9	9	7	7	7	7	8	9
E13	9	8	7	7	7	7	7	8
E14	10	7	6	7	5	6	6	7
AVG	9.57	8.14	7.64	7.43	7.00	7.07	7.14	7.93
DESV	0.51	0.66	0.84	0.51	0.88	0.73	0.77	0.73
VAR	0.24	0.41	0.66	0.24	0.71	0.49	0.55	0.49

On the other hand, as it can be observed in Table 9, barriers detected by carpoolers obtained in general lower values compared with incentives. Also, the values obtained are

higher than scores in a previous experience based on similar questions [31]. This could be motivated because the advantages perceived in the incentives, mitigated the disadvantage perception by the participants. The loss of independence while carpooling was pointed with the highest value (Item B4; AVG = 5.86). In a similar way, previous studies pointed loss of personal independence as an important barrier to adopt carpooling [35,48,58]. Some of the most frequently mentioned barriers in the literature include issues related to scheduling flexibility, trust among users, and concerns about the inconvenience of sharing rides. Such factors tend to introduce variability in responses, as the impact of these barriers may differ based on individual circumstances, such as geographical location, commuting distance, and personal preferences.

**Table 9.** Barriers detected by experts during their experience (Cronbach's Alfa = 0.678).

Item	B1	B2	B3	B4	B5	B6	B7	B8
E1	1	5	2	7	1	2	2	5
E2	2	5	3	7	1	2	3	5
E3	1	6	4	8	1	2	2	5
E4	1	4	1	6	1	1	2	4
E5	1	3	1	5	1	1	2	4
E6	2	4	3	7	2	2	4	3
E7	1	5	4	5	1	1	2	4
E8	2	5	3	6	1	1	3	3
E9	1	3	2	4	1	1	2	4
E10	1	4	2	6	1	2	1	4
E11	1	2	1	6	1	2	1	5
E12	2	4	2	6	2	3	2	3
E13	2	4	2	6	1	2	3	5
E14	1	3	2	3	1	2	1	5
AVG	1.36	4.07	2.29	5.86	1.14	1.71	2.14	4.21
DESV	0.50	1.07	0.99	1.29	0.36	0.61	0.86	0.80
VAR	0.23	1.07	0.92	1.55	0.12	0.35	0.69	0.60

#### 4. Conclusions

The results obtained demonstrated significant potential for reducing vehicle usage and environmental impact. Key conclusions based on the results are as follows:

First at all, a notable reduction of 31.9% in the number of vehicles on the road was achieved. While a 100% reduction was not feasible due to individual constraints, an optimal scenario could allow for up to 80% reduction if carpooling conditions (such as schedule and location matching) were maximized. The reduction in vehicle usage led to a saving of 109,080 km of travel over the course of 180 working days, with an average of 2537 km per carpooler. This decrease in driving distance directly resulted in a significant environmental benefit, with an estimated 16,362 kg of CO<sub>2</sub> emissions avoided, assuming an average emission of 150 grams of CO<sub>2</sub> per km and vehicle. These results underscore the environmental advantages of carpooling, aligning with previous findings on the reduction of traffic-related emissions through shared transportation initiatives.

Regarding the incentives to carpooling, the primary motivation for participants was fuel savings. This finding is consistent with previous literature highlighting the importance

of economic incentives, particularly those tied to fuel costs, as critical motivators for carpooling adoption.

In addition, the reduction of physical fatigue from driving was identified as the second most important incentive, which suggests that participants also valued the personal health and well-being benefits of shared commuting. This incentive has been corroborated by previous studies that emphasize the reduction in driving stress and fatigue as key reasons to adopt carpooling.

Also, social incentives, such as increased coworker support, socialization, and improved relationships, received lower ratings. However, all incentive items scored above 7, indicating overall positive perceptions of the carpooling experience.

Although barriers were also identified, their impact was generally lower than that of the perceived incentives. This suggests that the advantages of carpooling, such as fuel savings and reduced fatigue, may mitigate participants' concerns about potential downsides.

The loss of personal independence while carpooling was perceived as the most significant barrier. This finding aligns with previous studies, which also cited the loss of independence as a key obstacle to carpooling adoption. Factors such as scheduling flexibility, trust, and convenience were also noted as potential challenges, reflecting the diverse personal preferences and logistical considerations that can affect carpooling participation.

The variability in the perceived barriers indicates that carpooling programs could benefit from targeted efforts to address concerns such as scheduling flexibility and loss of independence. Tailored strategies, such as flexible ride-sharing arrangements or providing incentives for maintaining personal freedom, could help mitigate these concerns and increase participation rates. Promoting environmental benefits, in addition to economic incentives, could also broaden the appeal of carpooling. Although emissions reductions were rated highly, the direct economic impact of fuel savings was seen as more important by participants, highlighting the need for enhanced communication of the societal and long-term benefits of carpooling.

The study demonstrates that carpooling can significantly reduce the number of vehicles on the road, resulting in substantial environmental and economic benefits. While fuel savings and physical fatigue reduction were key motivators, barriers such as loss of independence and logistical challenges need to be addressed to maximize participation. These findings suggest that carpooling programs should focus on optimizing matching conditions and addressing individual concerns to promote wider adoption. The effectiveness of the system can promote similar experiences in other schools and other sectors.

In summary, while fuel-saving incentives stand out as the primary motivators for carpooling, further efforts should be made to communicate the broader benefits, such as emission reductions, to encourage wider adoption.

#### *4.1. Limitations*

Participants in the experience were selected from the same region in Spain. Specific characteristics of the region such as: climatic conditions, public transportation availability or traffic conditions could have influence in the results obtained.

The results were tested as reliable and consistent, however a bigger sample could provide results with different reliability.

Although results might be transferred to other types of trip, it is important to note that personal variables and matching rates will change depending on the journey conditions.

#### *4.2. Future Research*

Design of strategies and tools to increase the match rates among the potential participants, will increase the participants in future experiences, and it will encourage carpooling adoption. According to the current research, future experiences in different regions with wider samples of participants will extend the previous results. Additionally, new car technologies such as: electric, hybrid and autonomous vehicles might be included in the sample studied.

Similar experiences can be performed in other sectors with different conditions for a better knowledge of the carpooling variables in other working environments. It is important to bear in mind that replicability in other contexts will be conditioned by quality of key information such as departure and arrival zones, timetables, and available seats. This information will be the base of matching rates.

Finally, the development for the improvement of communication strategies to promote carpooling among potential carpoolers from the same sector, could increase carpooling adoption.

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## Abbreviations

The following abbreviations are used in this manuscript:

AVG	Average
B	Barrier
DESV	Standard deviation
E	Expert
I	Incentive
VAR	Variance

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