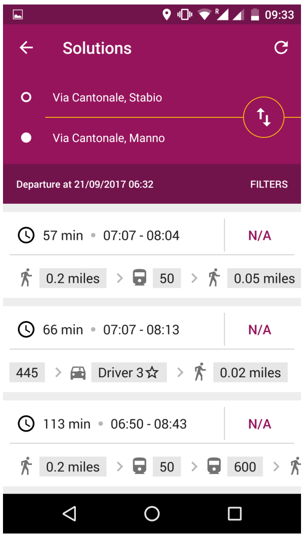

Challenges and opportunities in deploying a mobility platform integrating public transport and car-pooling services

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Abstract

This paper introduces a new mobility platform that favours reducing individual car use, by combining car flexibility with advantages offered by public transport, such as punctuality, comfort, safety and low environmental impact. Such platform services are delivered by means of a smartphone app that, thanks to advanced artificial intelligence algorithms, performs multi-modal vehicle routing by accounting for walking, public transport and car-pooling rides. To explore citizens' attitudes and perceptions towards SocialCar, and assess its overall business potential, we tested a prototype version in Canton Ticino (Southern Switzerland), engaging common citizens and their everyday mobility needs.

In this paper we first present the app and the route planning algorithms we developed to match travel demand and offer, commenting on the challenges to be addressed when using real-life data (shortcomings in mapping, public transport and car-pooling data). Then, we describe the methodology used to assess the SocialCar overall potential, based on focus group meetings run before and after the field test, and summarize the results obtained, in terms of strengths, weaknesses, threats and opportunities for a large-scale diffusion of the SocialCar platform. Finally, we comment on the lessons learnt and provide recommendations for future similar "mobility as a service" platforms.

Keywords

public transport, carpooling, multi-modal routing algorithms, artificial intelligence, field test

1 Introduction

Even though worldwide promising signals show that a peak in car use has already taken place (Newman and Kenworthy, 2011), in many European cities solo car use is still the dominant mode of transport. Public transport is often criticized due to lack of frequency, spatial coverage, flexibility and easiness of interchanges (see for example Cellina *et al.* (2016)), and in some cases, alternatives to solo car use exploiting public transport alone, simply do not exist. In other cases, they impose lengthy walks and/or time-consuming multi-leg journeys, which are not convincing as viable alternatives to door-to-door car routes. Alternatives such as (dynamic) car-pooling or ridesharing are gaining popularity, though they are not always available, since matches between demanded and offered trips are not easy to be found, if a critical mass of user is not reached (see for example Handke and Jonuschat (2013)).

In such a framework, overcoming the traditional competition between private and public modes of transport, envisioning instead a fruitful collaboration among them, would be a win-win approach. This is the challenge of SocialCar, a multi-modal mobility platform that extends public transport networks, by evolving them in social and intelligent mobility networks. Exploiting open traffic data and artificial intelligence algorithms, SocialCar integrates public transport and car-pooling services, making them available by means of a smartphone app, which allows planning and booking for multi-modal trips, combining rides offered by other citizens with regular public transport routes. It envisions a sort of a "Public-Private-People Partnership" for urban transport, as defined by Majamaa *et al.* (2008), where public transport companies, car-pooling companies and citizens collaborate to the co-production of a new mobility service, which offers multi-modal, time-effective and flexible on-demand mobility options. However, citizens might be distrustful towards this new multi-modal mobility option, due to resistance to change over established habits, lack of familiarity and perceived risks associated with interchanging from one mode to another. To assess SocialCar potential and analyze its overall level of acceptance, strengths and weaknesses, field tests were run in different European sites, including Switzerland.

In this paper we first introduce related work (Section 2), then present the SocialCar app (Section 3) and the route planning algorithms we developed to match travel demand and offer, commenting on the challenges we addressed when using real-life data (shortcomings in mapping, public transport and car-pooling data) (Section 4). Then, we introduce the Swiss field test used to assess the SocialCar overall potential and summarize the results obtained, in terms of strengths, weaknesses, threats and opportunities for a large-scale diffusion of the SocialCar platform (Section 5). Finally, we comment on the learned lessons and provide recommendations for future similar "mobility as a service" platforms (section 6).

2 From carpooling to Mobility as a Service schemes

Car-pooling (also known as ride-sharing) has a long history and has been widely studied, to understand which segments of population are most likely to adopt it and identify drivers and barriers to its large-scale adoption (see for example Oppenheim (1979), Ben-Akiva and Atherton (1977), Margolin *et al.* (1978), Teal (1987)). Literature emphasizes that, notwithstanding its high potential, traditional carpooling options have not been able to take off as an alternative to solo car use, in particular for short-range carpooling at the urban level. Recently, car-pooling benefited of renewed interest (Chan and Shaheen (2012), Vanoutrive *et al.* (2012), Furuhata *et al.* (2013)), thanks to the development of real-time, just-in-time algorithms capable of matching demanded and offered rides, made available by progress in information and communication technologies, and the diffusion of mobile devices and location-based services (Amey *et al.* (2011), Agatz *et al.* (2012), Cici *et al.* (2014)). The parallel emerging of the sharing economy further facilitated creation and diffusion of new mobility businesses, which provides car-pooling with new opportunities for development (Cohen and Kietzmann, 2014). In this context, in fact, web and app-based travel assistance services quickly spread, frequently triggering changes to the operational models of conventional transport providers, such as public transport providers and taxi companies, by promoting greater cooperation and flexibility. From initial mono-modal journey planners, which allowed users to identify the best route connecting an origin and a destination at a given time and with a given means of transport, by optimizing travelling time, cost or environmental impacts, mobility planning tools fast evolved towards multi-modal journey planners, exploiting map-matching algorithms and real-time data collected by location-based services. A fast growing sector, such tools are now further evolving in Mobility as a Service (MaaS) schemes (Kamargianni *et al.* (2016); Jittrapirom *et al.* (2017); Mulley (2017)), offering multi-modal mobility packages able to address most of the user's mobility needs. With the convenience of a single payment point, and real-time updates on journey planing based on traffic conditions, advanced MaaS schemes create viable alternatives to car ownership and can re-launch carpooling, by explicitly including it among the offered transport options.

In this framework, the SocialCar mobility concept was developed within a H2020 EU-funded research project (Wright *et al.,* 2018), with the following main aims:

- overcoming the limitations of current carpooling practices, moving from long trips to effective urban use;
- developing a new carpooling approach, targeted to optimise the inter-modality system of carpooling with existing transport and mobility services of EU cities.

The result is a mobile app combining the flexibility of car-pooling with the advantages offered by public transport.

3 The SocialCar mobile app

The most tangible outcome of the SocialCar project was a mobile app, named *RideMyRoute* but for the sake of simplicity here referred to as *SocialCar*, that helps users finding optimal routes to satisfy their mobility needs (reaching a given destination at a given time), considering all mobility options resulting by adequately matching public transport, car-pooling and walking.

User interface and main functionalities of the app were designed and developed by partners of the SocialCar H2020 project, while our research team developed the multi-modal route planning algorithms. The app was then tested in different European sites, under increasing level of complexity: in ten sites app-use was simulated during workshops attended by local authorities stakeholders, including public transport and car-poooling providers and environmental associations. In five of such sites, a survey targeting common citizens, as potential SocialCar users, was held as well, providing insights on the expected level of acceptance of the app and the related mobility service. Finally, in four of such sites also a real-life, four-week field test was held, to understand SocialCar's opportunities and drawbacks directly from the perceptions of common citizens. Canton Ticino is included among the sites where the field test was run, under coordination by our research team.

The paper focuses on the field test, presented and discussed in detail in Section 5. Here, we introduce the main functionalities and characteristics of the app, which is available for Android and iOS operating systems. After logging in and shortly specifying their profile preferences, both as *drivers* and as *passengers*, SocialCar allows users to either offer a ride or ask for journey options connecting two given places at a given time. To ask for a ride, passengers are requested to enter their starting and arrival points and to specify the day and hour. The same piece of information is requested to drivers offering a ride; in such a case, the system automatically estimates the path the driver is expected to follow and the related travelling time, being therefore able to infer when the driver will find herself in any of the points along the identified path, thus generating an implicit "timetable" for the car pooling route. In the current version of the App users have no possibility to manually modify either the path of the route or the estimated travelling time. Any single ride drivers wish to offer has to be individually inputed; this also holds for systematic routes, such as those they are used to travel for work or study purposes.

When a passenger seeks for a ride, a multi-modal route planning and ride-matching engine is activated, which takes into account walking possibilities, public transport time-tables, car-pooling rides offered by drivers, and any disruption in the related time schedules, if real time traffic information is available. As a result, the app provides the passenger with a number of full-length trip proposals, that can include carpooling, public transport and walking legs (see Figure 1 for some examples of the app user interface). If she selects one proposal including a carpooling leg, she can contact the driver via SMS or phone call to get details on the ride, and can then book the ride directly from the app. Her booking request is sent to the driver, who is free accept or reject it. The booking procedure is only completed when the driver approves the request, and the planned ride is stored in a dedicated page of the app, both for the passengers and for the driver. A notification system guarantees informations on requests and approvals are timely conveyed to both passenger and driver.

To simplify the user mobility experience and to reduce the risk of missing connections due to traffic or any other reason for delay, carpooling legs are only offered either at the beginning or at the end of the whole trip. In between, public transport and walking legs are offered. If more options are found, users can order them by overall travel time or cost (both estimated by the system).

Finally, to overcome resistance to carpooling due to the fear of sharing rides with strangers, a user feedback and rating system is included, directly connected with social networks: after every ride, both passengers and drivers are requested to rate their travel companion and can share their assessment on Facebook. The rating feedback is based on a five-star scale and requires to express an overall assessment and six specific assessments regarding comfort, punctuality (starting and arrival time), respect of the agreement on the route to be followed, style of driving and pleasure as a travel companion as well. Leaving an open comment is also possible.

4 The SocialCar multi-modal route planning algorithms

In a previous work by Jamal *et al.* (2017) we presented a review of real time route planning and ride matching algorithms used by the most popular route planning applications. In short, most state-of-art algorithms for map routing are based on Dijkstra's algorithm for shortest-path computation. The performance of that algorithm has been then improved using variations based on contraction hierarchies that generate shortest-path routes more efficiently than Dijkstra's algorithm; arc flags is another approach to speedup the shortest-path computation by avoiding the exploration of unnecessary paths during the shortest-path computation query. Finally, the A*

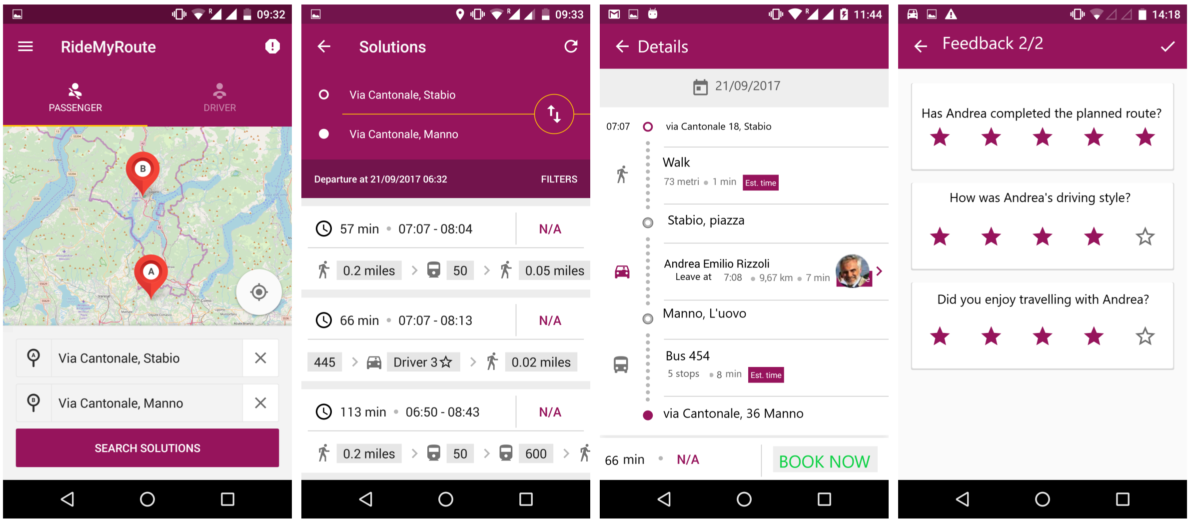

Figure 1: Addressing one's mobility needs with SocialCar. From left to right: the passenger indicates desired starting and arrival points; SocialCar indicates the list of available mobility options; the passenger selects one option and gets the full sequence of its legs. Once the ride has taken place, both passenger and driver are requested to leave a feedback on each other.

algorithm is a generalization of Dijkstra's algorithm that reduces the size of the subgraph that must be explored.

In the context of the SocialCar project we had to solve the problem of finding the shortest path in time, while allowing for modal changes of the means of transport. This problem requires the organisation of transit data in a multi-layer temporal network: each transportation mode (e.g car, foot, train, bus, etc.) has its own network, and switches from one mode to the next one are allowed only in correspondence of so called "switch points". In the multi-layer temporal network, the travel time depends on both the arrival time at the starting point and the means of transport used to reach the target point, therefore the travel time changes during route computation.

A specific problem was therefore posed by the integration of carpooling offerings as one of the potential transport modes, to be formatted in specific layer of our temporal network. Such offerings could be either generated within the SocialCar app, by users acting as drivers, or even by integrating data provided by external carpooling companies in order to enlarge the potential number of SocialCar adopters.

Carpooling offering in SocialCar has been successfully modelled by extending an existing standard for carpooling data exchange (the RDEX standard [1]) with GTFS-like information, thus assimilating carpooling to a-periodic public transport services. We used this standard to describe the carpooling offering generated within the app, but also carpooling providers in our four test

[1] http://www.feduco.org/articles/actus/rdex/

sites agreed to export their offered rides according to it. The synchronisation of external rides took place according to a pre-determined frequency (usually once per day) so that SocialCar could import those rides and offer them to the SocialCar users. In case a passenger selected one of those rides, she was redirected to the website/app of the offering company, where the finalisation of the ride matching took place.

A related issue in the integration of carpooling rides in SocialCar was the matching of the travelled routes with the potential switch points. As discussed, the key strength of SocialCar is the ability to combine public transport and carpooling. Clearly the modal exchange works best if it happens in the vicinity of a public transport stop. Yet, the typical carpooler only inserts the origin and destination, departure time and arrival, and it does not provide the route information. In this case, the SocialCar algorithm had to generate a potential route to be validated by the user and also propose optional modal exchange points (i.e. stops) along the inserted route, in order to allow for the modal exchange of passengers.

The advantage of a multi-layer temporal network structured as we have just described is that traditional shortest path algorithms work with little modifications, but in order to find routes that are better suited to the users' preferences, we modified the single objective function of the original Dijkstra's algorithm by adding more objectives including transportation time, walking time, and the number of modal changes. The solution to the problem is then found by minimising a weighted sum of the above objectives. Details on the algorithm and the data structure supporting it can be found in Jamal *et al.* (2017).

The solution of the multi-objective optimisation problem outlined above put a considerable load on the computational burden on the algorithm. In order to maintain the response time at an acceptable level, we opted for the parallelization of the computation. The same route planning task was split into a number of identical tasks, with different values of the weights attributed to the various factors affecting the computation of the solution (transportation time, walking time, and the number of modal changes). This method of weight perturbation allowed us to generate multiple solutions which were more likely to include a solution that matched the user's expectations.

4.1 Challenges due to use of real-life data

The SocialCar algorithm has been developed as a key component of the SocialCar project with the stated objective of making available concrete solutions for the integration of car pooling in public transport. This aim required the creation of an algorithm to be tested in the real world, against real data, with real users. Data availability (both quality and quantity) has thus proven to be the biggest hurdle for the successful implementation and deployment of SocialCar. We started by making a distinction between *static data*, pertaining to those data whose update frequency was limited (e.g the road network extracted from *cartography data*, the *public transport timetables*), and *dynamic data*, which is frequently updated, such as *car pooling offerings*, real time information on the public transport network state, and *real time traffic information*, such as notification of traffic accidents and road works. One might think that static data can be easily obtained, and its quality is sufficient for commercial purposes, but this is true only when you are not dealing with free openly available data, as it was the case for the SocialCar project, which made a point of using Open Data.

Regarding cartography data, at the start of the SocialCar project, for all the involved test sites, a choice was made to rely on Open Street Map cartography (OpenStreetMap Foundation, 2018), which was assessed as particularly appropriate for a research project. Unfortunately, more frequently than expected, automatic location of certain street addresses was wrong. Namely, when OSM was unable to map an address string to a known location, it automatically located the address inserted by the user in another position, identified according to internal rules (usually defaulting to the city centre). As a consequence, since the route planning algorithms were launched after the automatic location of addresses, routes suggested to passengers were frequently incorrect, and since OSM did not return an error code, the SocialCar app did not notify the user of the location problem. Therefore, only users who were carefully checking the maps, were aware of the problem, and especially were capable of understanding why the suggested path was wrong. This error was particularly critical when users were asking for rides towards places that they did not know very well.

For public transport data, most public transport companies publish data using the GTFS (General Transit Feed Specification) format which was originally proposed by Google. The simple fact that Google offered to include public transport information in Google Maps provided that it adhered to the GTFS standard, made it a successful "de facto" standard. In SocialCar we therefore had to comply to this standard, and while the quality of data for the road network was overall sufficient, the same could not be said for public transport data, as its quality and coverage varied a lot across the pilot sites. The SocialCar algorithm was tested in four cities, and only in Brussels and Canton Ticino data was of a sufficient quality (despite some glitches). In Edimburgh, for instance, it was not possible to acquire a GTFS (General Transit Feed Specification) feed of the various train services. For the Swiss pilot, we realised only during internal testing that an entire railway route was missing (S60: from Lavena Ponte-Tresa to Lugano), which led the system to suggest to users time-consuming carpooling legs instead of the time-efficient train legs. In other cases, errors were even more sneaky, since some stops were missing in some services, thus producing routes forcing the user to alight at the next station and then backtrace. We might say that a side result of the project was the message to the European Commission that much needs to be done in the area of opening up the public transport data sources.

Regarding dynamic data, we faced the problem of how to provide high quality and up to date information on the state of the transit networks we considered: from the road network, to the public transit real-time information, while relying on publicly available Open Data. This proved itself to be impossible in practice and it was therefore decided to acquire commercial traffic information available in the different sites, but even that was of insufficient quality. The road accidents were communicated by giving the type of accident and the position; the traffic flow direction, an essential piece of information, was instead not included in the information we had available. Higher quality information is often used uniquely by the data owner itself, as it happens for Google, which publishes maps with colour coded traffic information (dark red for a blocked road, red for intense traffic, and green for free flowing traffic), but it does not release the actual figures (e.g. average travel times on road segments). The SocialCar algorithm has anyway been designed in order to make use of such a coarse information, so that when a traffic accident notification is raised, the algorithm finds an alternative solution which tries to circumvent the affected area.

5 The SocialCar field test in Southern Switzerland

The SocialCar app and services were field-tested between November 2017 and February 2018 in the four European sites involved (Bruxelles, Edinburgh, Ljubljana and Canton Ticino), with the aim of understanding their potentials and limitations by the direct experience of common citizens. Here we summarize what happened in Canton Ticino.

5.1 Challenges due to interaction with real-life users

As in any real-world experiment the main challenge we faced was the recruitment of a critical mass of users. In the next section we discuss the recruitment strategy we adopted, but here we detail how we tackled a problem that was well-known from the beginning of the SocialCar project: how to guarantee a sufficient amount of routes offered by drivers. Finding users willing to test multi-modal solutions including public transport and carpooling is one issue, but finding drivers willing to share a seat in their car is a totally different problem. And, as in all systems that include carpooling, the launch of the system is the most critical stage. In fact, if only passengers are attracted by the system, they will start asking for rides, finding no matches, since no drivers offered them. Therefore, the system might soon look non interesting at their eyes, and they would soon quit using it, thus precluding its roll-out. To avoid this situation, we opted for making a number of offered routes available from the very beginning of the field test. To this purpose, we joined forces with an already existing car-pooling provider in Canton Ticino, BePooler SA, who already had a fair number of users in the area. The agreement signed between SocialCar and BePooler allowed SocialCar to include among its data-base of offered routes also the routes that had been offered by BePooler drivers. In case a SocialCar passenger asked a ride offered to a BePooler driver, the BePooler app would automatically open on her phone, allowing her to complete the request and conclude booking. This procedure solved the lack of a critical mass of offered routes. However, it was not fully friendly for the passengers, who had to register and interact with two apps (the SocialCar and the BePooler one) in order to complete their booking. Also, since the two apps were characterized by different route planning engines, letting them fully interact was not possible, and some simplifications where required, which in some cases did not allow passengers to find exactly the same route in the two apps.

Finally, a key challenge that SocialCar decided not to engage into refers to how to manage all the aspects related to payment. Some carpooling apps, such as the BePooler one, create a virtual currency that allows passengers and drivers to exchange credits, proportional to the number of kilometers that they share, which can later on be redeemed for other goods or services. Since developing a strict "electronic wallet" system was assessed as too complex for the SocialCar prototype, which is just developed within a research project and has no ambition to be directly used as a commercial product, it was decided to on purpose leave any aspects regarding ride payments outside of the SocialCar app.

5.2 Recruitment of participants

Guaranteeing a diverse enough group of participants regarding their socio-economic characteristics, in order to consider them representative of the whole population and to draw general-value conclusions, was a pre-requisite. We added another requirement as well, namely that participants to the field test had to at least share either the starting or the arrival point of most of their trips. Opening the test to anybody across the whole Canton Ticino, which spans for more than 100 kilometers from Airolo to Chiasso, would have not allowed us to guarantee the needed critical mass of offered rides for carpooling services to be effective. For this reason, we decided to focus on the Lugano region, which is the most populated of the Canton, has the highest concentration of workplaces and also has a good supply of public transport routes (Milan-Zurich international railway route, Chiasso-Bellinzona and Ponte Tresa-Lugano regional railway routes, plus additional urban and extra-urban road bus routes). Recruitment of participants to the field test was therefore performed by means of a public open call, targeting people either living or working in the Lugano area. Invitation to join the test was communicated by means of a press conference; in parallel, a network of local partners and local stakeholders were activated in order to invite their members and affiliated citizens, through their newsletters. Also, paid advertisement was performed through social network channels.

Participants to the test were requested to actively use the SocialCar app, either looking for rides (as *passengers*) or offering them (as *drivers*) for at least three times per week for three weeks out the whole test period, which run from November, 6 to December, 8 2017. They were also requested to answer two online surveys and attend two focus group meetings (one immediately before and one immediately after the test), to assess their attitudes and perceptions towards the SocialCar system, and to notify any errors or proposal for improvement, by means of an online form. As an incentive to participation, and in return for their efforts, they were attributed the following rewards:

- one free weekly public transport season ticket for the first twenty subscribers to the test;
- eight vouchers of the value of 100 CHF each for the most active users (the one who offered most rides, asked for most rides, completed most rides, notified most errors/proposals for improvement), which were attributed at half the test and at the end of the test;
- a final raffle among participants remaining active until the end, offering a folding bicycle, ten monthly seasons tickets for public transport and five smartphones.

Communication activities were launched two weeks before the start of the field test. The recruitment period closed with 76 voluntary citizens who formally signed in as SocialCar testers. Additionally, another 41 citizens registered on the app, which was publicly available on iOS and Android stores for download, but did not take part in the activities planned for the test (surveys, focus group meetings) **or** enter the incentive scheme.

5.3 Overall assessment

The trial opened with an initial meeting (either in-person or via online webinar), during which the overall SocialCar project was introduced and a tutorial of the app was offered. In total, 42 people attended such meeting, either in person or online, out of the 76 who had formally signed in to join the test. During the testing period, both email and phone support was offered to the testers. We also sent them email communications at half and at the end of the test, to announce prize winners, provide them with practical updates about the test and keep their interest alive. Table 1 summarizes its quantitative results in terms of rides asked for, offered and actually shared during the testing period.

Overall, 2'450 searches for routes were performed by passenger users, on average equal to 32 searches per user, which, out of the four-week testing period, is a bit more than one search per user per day. Every search resulted on average in four suggestions of routes, for a total of 9'801 solutions returned to passengers. Offers for rides by drivers were instead 398, on average equal to 5 offers per user, which is a definitely smaller value. This is probably due to an intrinsic limitation of the SocialCar app, which imposted to manually enter each single ride offered and did not offer advanced possibilities to input offers of systematic rides in a bulk, thus providing a barrier to friendly app use as drivers.

Of the 9'801 routes solutions returned to passengers, 21% (2'084 solutions) included a carpooling leg, and 2.9% (281 solutions) included *only* a carpooling leg. The remaining 79% of solutions (1'803 solutions) only included public transport or walking legs. This means that theoretically speaking SocialCar managed to expand by around 20% actual possibilities to find solutions for a given trip, with respect to commonly used mono-modal journey-planners, such as the one by the Swiss Federal Railways (2018).

However, if we consider the overall number of route solutions returned to passengers that include a carpooling leg (2'084 solutions), figures show that only 2.1% of them (44 solutions) were assessed by passengers as interesting as to send a booking request. These figures therefore show a very limited practical impact of the SocialCar innovative elements: even though SocialCar significantly expanded the possibility to find route solutions, for 97.8% of the searches for routes by passengers, such solutionswere assessed by passengers as not competitive with respect to alternatives already available to them - and in fact they did not ask to book them. This limitation is strictly connected to the low number of users and especially the low number of offered rides, which appears even more evident if compared to the wide extension of the mobility network of the Lugano region in Canton Ticino. Without a critical mass of drivers offering rides, interesting matches keep being difficult to be found.

Finally, we remark that not all of the 44 rides for whom a booking request was sent via the app, were actually accepted by drivers and therefore shared in real life. In fact, the number of completed carpooling rides is only equal to 32, which is 76% of the booking requests. This might be due to personal reasons of the users, mostly external to the app, related to changes in their daily programmes and consequently in their mobility needs.

Table 1: Summary of the quantitative results of the SocialCar field test in Canton Ticino.

Field test in Canton Ticino (November, 6 - December, 8 2018)	
Number of registered users ("drivers" and "passengers")	76
Number of registered users offering rides ("drivers")	35
Number of offers of rides by drivers	398
Estimated number of searches for routes by passengers	2’450
Number of route solutions returned to passengers	9’801
Number of route solutions returned to passengers that include a carpooling leg	2’084
Number of only carpooling route solutions returned to passengers	281
Number of carpooling and public transport route solutions returned to passengers	1’803
Number of booking requests for carpooling rides	44
Number of accepted carpooling rides	32
Number of notifications of error via the online form	41
Number of proposals for improvement via the online form	61

To get insights on these results, soon after the end of the testing period we held a series of focus group meetings, again either in person or via online group conversations. We were in particularly aimed at collecting opinions and perceptions on the SocialCar system and concept, in order to evaluate its strengths and weaknesses.Overall, 19 testers attended such post-test meetings. Outcomes of the discussions highlight testers had a general positive opinion towards SocialCar and the underlying concept, notwithstanding a series of limitations they found.

5.3.1 Strengths

Many of the testers involved in focus group meetings were car drivers, who declared they had offered a few rides through the app. As SocialCar "drivers", they were motivated by both egoistic and altruistic reasons: when asked about their motivations, they explicitly mentioned the possibility to reduce traffic, which would have allowed them to move faster across urban areas, and to help other people. For such "drivers", using SocialCar had not implied introducing significant changes in their mobility patterns, since they kept using their car, just offering a ride from time to time. This was why they were particularly positive about SocialCar: while keeping their autonomy and independence, they were still giving their contribution to reduce traffic congestion and the related environmental and energy impact, in favour of their own community.

Other testers who joined focus group meetings were public transport users, mainly looking for rides as "passengers". Overall, they assessed SocialCar as positively as drivers: they appreciated the opportunity to reduce their travelling times and related costs, by combining public transport with carpooling rides. Public transport in Canton Ticino is in fact usually assessed as quite expensive for the occasional ride, and testers expected any ridesharing fees to be lower than current public transport ones. However, as the number of carpooling rides actually performed during the test was so low, it appears their positive assessment mostly refers to the general SocialCar concept than their personal experience with public transport and car-pooling during the test.

A possible drawback, to be further investigated, is that triggering public transport users to abandon solo public transport and move to a combination of carpooling and public transport, in the long-term might be counterproductive, from a global sustainability perspective. The target group to address for future SocialCar-like interventions should therefore be better made of car drivers and people already used to both car and public transport. In any case, all categories of testers remarked usefulness of SocialCar for both systematic and non-systematic trips.

Another strength of the SocialCar system was seen in its flexibility: since it includes different means of transport, "passengers" reported they had no fears about difficulties on their way back, in case they shared a carpooling ride on their way to. It was remarked, however, that such a positive judgment was possible since all "passengers" had quite flexible mobility needs and could arrange their trip back home based on the availability of means of transport: in case of any problems preventing carpooling solutions on their way back, they could have always used public transport to go back home. Some other testers, less flexible due to the need to accompany their children, would have however appreciated the possibility to book "return packs", instead of one-way rides, directly from the app.

During focus groups we also assessed testers' perceptions about safety issue: the majority of them reported they were not afraid of sharing rides with unknown persons and, to the contrary, saw in SocialCar an opportunity to get acquainted with new people and get entertained while travelling.This was especially true to those who had earlier used long-range carpooling services like BlaBlaCar (Arcidiacono and Pais, 2016): previous good experience with other carpooling systems seems to be an enabler of positive SocialCar experiences. Only one male tester stated that, even though he had offered rides as a "driver", he had opted for cancelling it, due to anxiety about the possible passenger's characteristics (whether he/she had valid documents, whether he/she was ill-intentioned, ecc.). A couple of female participants replied confirming they were a bit uncomfortable with the general concept of carpooling, though they were reassured by the fact they were participating to a research project, with the local university somehow guaranteeing for responsible behaviour of the involved testers. Interestingly, the group of testers also noted that the majority of requests and offers for rides were related to daytime hours: night rides were probably assessed as pretty critical from the safety point of view, thus being excluded from SocialCar on a prior basis, both by "drivers" and "passengers". In any case, the star-based rating and reputation feed-back system offered by SocialCar was unanimously appreciated and positively assessed as an effective tool to create trust among app users.

The last topic for discussion concerned privacy. A tester had offered rides while commuting to work, when he was already used to giving a lift to school to his sons. No match was found with requests by "passengers" and he never received booking requests; however, he was a bit worried about how to integrate a stranger passenger in such a "family trip", during which they usually discussed about school and family-related issues: commuting was one of the rare occasions he had to talk with his sons, which would have been "spoiled" by the presence of another person. To him, this privacy-related aspect would actually have been a small barrier to regularly offering rides on his commuting trip. Other fears related to privacy, those related to location service functionalities, were instead regarded as not critical at all: most of the testers had enabled location services functionalities, even though not strictly necessary for SocialCar to properly work, and in general they were neutral with respect to this aspect and the related privacy issues, agreeing to being tracked.

5.3.2 Weaknesses

The main critical issue raised by testers was related to the low number of carpooling trips they were suggested, as already indicated: due to the low number of participants in the test and technical limitations in the app, the solutions proposed by SocialCar were mainly based on public transport alone. Out of the 19 testers who attended the focus group meetings, in fact, only two couples managed to share a ride thanks to SocialCar - and for one couple, the same ride was repeated a few times during the test, since it was a systematic trip for commuting to their workplace. Besides the low number of testers in absolute values, which physically precluded finding a large amount of carpooling matches, the low number of offered rides could also have been related to technical limitations in the app.

In fact, testers remarked the whole "carpooling experience" was not user friendly enough in the app, and this might have been a barrier to regular interaction with the SocialCar system. First of all, testers highlighted as particularly critical the limitations in accuracy of automatic location on the map, accompanied by the lack of possibilities to manually edit the path and expected travel time, when offering a ride. The automatic assumptions about them made by the SocialCar system were in fact frequently assessed as underestimated ("does it really take traffic conditions into account?"), or simply were different with respect to their mobility patterns, which lead "drivers" to lower trust in the system and to offer rides less frequently than they could have. Also, "passengers" would have liked to be allowed to look for a destination by just inserting a label characterizing it, such as station, hotel, hospital ecc., instead of their full address, which frequently is not known.

Then, testers also complained about the lack of communication channels between "passengers" and "drivers" directly inside the app. Relying on an internal chat would have been preferable, instead of being compelled to spend money in phone calls or SMS messages, as in SocialCar. Also, introducing possibilities for the "passenger" to monitor in real time the position of the "driver", when getting close to the carpooling inter-change point, and vice-versa, would have been definitely appreciated, allowing them to better manage any delays or anticipations. Under such a system, punctuality of both "passengers" and "drivers" could also have been automatically assessed and included into the user reputation, to increase trust in the rating systems.

Finally, both "drivers" and "passengers" expressed dissatisfaction for the need to one-by-one insert every single ride. One "driver" proposed to even go further in automating inputting a series of recurrent rides: why not directly allowing SocialCar to access one's calendar and infer the need for rides, automatically providing a "passenger" with a notification about the available SocialCar options? A similar system would also allow automatic input of ride offers by "drivers". Such an automatic approach would have also addressed another barrier to the active use of SocialCar, acknowledged by some testers, both "drivers" and "passengers": they noted planning a ride in advance is not always easy or possible, in case it is a non-systematic, short-range one: one might decide when to leave and by which transport mode very little in advance with respect to the departure time. Finally, testers notified they experienced stability issues, which caused the app to frequently crash and need to be restarted.

6 Discussion and conclusions

As a final assessment, overall opinion of the testers of the SocialCar system was quite positive. They appreciated the SocialCar idea to combine public transport and carpooling and declared that, provided the current technical limitations on the app functionalities were addressed and user experience was simplified, they would still be interested in using a SocialCar-like service in the future, thus producing a tangible impact on their mobility behaviour. In fact, even though the SocialCar project is now concluded and the app no longer available, its APIs have been publicly released, as well as the source code under the MIT license, so that any interested party can exploit its algorithms, software code or any other produced material, and integrate it in their offer for mobility services, for business purposes. To identify opportunities for commercial exploitation of the SocialCar product, the tests in each pilot site has been closely followed by a group of stakeholders, active in the mobility and environmental fields. Regarding the pilot field test in Canton Ticino, such stakeholders still assessing if and how integrating elements from SocialCar in their offer. Apart for technical limitations of the app, which could be "easily" addressed, provided that time and money resources are available, the main critical issue which clearly emerged from the field test is the difficulty to raise the interest of a sufficient amount of citizens, so that the critical mass needed for effective diffusion of carpooling services is reached. How to engage those citizens who are not spontaneously interested in changing their mobility patterns? This is is still an open problem for SocialCar - and actually it has been widely explored and investigated by behaviour change interventions in the social sciences, without finding universally-valid solutions. One possibility to be further explored, which has already proven effective in solo car-pooling initiatives (Vanoutrive *et al.,* 2012), could be to promote use of a SocialCar-like service in the framework of mobility management services for companies. Starting to appreciate the service for job-related, systematic trips, where trust is higher and finding a match is easier, since employees share the destination of their trip, employees might end up in keeping to use it also for their leisure trips. Another option might be to integrate a SocialCar-like service in already existing and widely used journey planners, such as for Switzerland the one of the Swiss Federal Railways (2018): doing so, at least half of the users, namely "passengers", would already be available. To raise the interest for "drivers" and stimulate them to offer rides, an incentive-based strategy could be implemented, exploiting gamification techniques (Deterding *et al.,* 2011). Gamification refers to the use of game elements in non-game contexts, such as for example attributing points whenever a ride is offered, rewarding with badges to celebrate the most active users and providing them with leaderboards to compare their performances with the other users. In such a framework, car drivers might first be attracted in the system by tangible prizes, such as the incentives we used in the SocialCar field test; then, such tangible prizes might be gradually replaced by virtual ones, in a gamified approach: once users enter the system, virtual prizes might promote their retention. In any case, we conclude by remarking that exploiting a new mobility service offered by an app alone cannot solve all mobility-related problems affecting a given region: wide diffusion of SocialCar-like services cannot happen without interventions aimed at guaranteeing constant improvement and level of effectiveness of public transport services.

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