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Trust me if you can: Practical challenges affecting the integration of carpooling in Mobility-as-a-Service platforms

Francesca Cellina [a,*], Marco Derboni [b], Vincenzo Giuffrida [b], Uroš Tomic [c], Raphael Hoerler [c]

[a] University of Applied Science and Arts of Southern Switzerland (SUPSI), Institute of Applied sustainability to the built environment (ISAAC), via F. Ruchat-Roncati, 15, Mendrisio 6850, Switzerland

[b] Dalle Molle Institute for Artificial Intelligence IDSIA USI-SUPSI, via La Santa 1, Lugano 6962, Switzerland

[c] Zurich University of Applied Sciences (ZHAW), School of Engineering, Institute of Sustainable Development, Technoparkstrasse 2, Winterthur 8400, Switzerland

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ABSTRACT

App-based Mobility-as-a-Service (MaaS) platforms combining public transport, car- and micro-mobility-shared services with real-time dynamic carpooling are emerging as viable alternatives to solo car use for sub-urban contexts. Insights from real-life implementation are however still limited. Which practical conditions may hinder the effectiveness of MaaS platforms leveraging carpooling? We tackle this question from the perspective of potential users of MixMyRide, a Swiss-based MaaS platform, based on co-design workshop sessions performed in Summer-Autumn 2022. We find four elements of practical interest, resonating with limitations already identified for carpooling. First, integrating carpooling in inter-modal trips increases the number of inter-changes potentially affected by delays. This requires real-time traffic information data, re-scheduling tools, and features for quick interaction between platform users. Second, features to create trust between strangers are needed, which require trade-offs between strict identity check and quick registration. Third, carpooling pick-up/drop-off may either endanger safety (if bus stops are used) or require inconvenient prior agreements, negatively affecting the MaaS platform's dynamism. Fourth, carpooling offer is not granted. To accept possible discomfort in sharing personal space with strangers and time-effort to enter trip offers, drivers need specific incentives, such as sharing of travel expenses, reward vouchers by public institutions, or virtual gamification and feedback on saved emissions.

1. Introduction

Digitalisation and the sharing-economy enabled unprecedented opportunities to enhance inter-modal mobility (Gebhardt et al., 2016; Willing et al., 2017) and replace solo car use, by means of app-based Mobility-as-a-Service (MaaS) schemes that integrate public transport, car and micro-mobility shared services (bicycle, e-scooter) in the same trip (Kamargianni et al., 2016; Jittrapirom et al., 2017; Li and Voege, 2017; Mulley, 2017; Shaheen and Cohen, 2020; Polydoropoulou et al., 2020). In urban areas, MaaS schemes are expected to create viable alternatives to solo car use and even to car ownership (Sochor et al., 2015; Matyas and Kamargianni, 2019; Schikofsky et al., 2020; Ho et al., 2020; Hoerler et al., 2020). Low-density and sub-urban contexts, typically under-covered by public transport and shared-mobility options, are not exempt from MaaS potential benefits, provided that they include additional mobility offers, such as for instance on-demand mobility services (Shaheen and Cohen, 2020). A promising approach that is emerging for such contexts could also consist in the integration of real-time dynamic carpooling services (Créno, 2016).

Carpooling has been broadly defined as the situation in which "two or more participants agree to travel together in a private car, belonging to one of the participants" (Neoh et al., 2018, p. 129). More specifically, Amirkiaee and Evangelopoulos (2018) (p. 10) provided a definition of carpooling as "any use of an automobile that includes, in addition to the driver, non-dependent passengers, without a fully commercial/formal relationship, with an agreement to share the ride, and with or without sharing the travel costs". Dynamic carpooling is a particular type of carpooling, which is based on an automated process through which "drivers" and "riders" are matched to share a ride on very short notice (from a few minutes to a few hours before the trip starts), without long-term arrangements (Agatz et al., 2011).

In many Western countries, average car occupancy rate is low. For instance, for Switzerland in 2021 it was estimated in 1.53 persons/vehicle (BFS/ARE, 2023), which provides plenty of opportunities for

* Corresponding author.
E-mail address: francesca.cellina@supsi.ch (F. Cellina).

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carpooling rides to be offered. Leveraging car drivers already travelling on the road and their available car seats could help to tackle critical first and last mile connection problems (Reck and Axhausen, 2019) to/from less dense and frequent public transport stops and routes, as well as to/from shared micro-mobility stations, thus addressing one of the most critical reasons why in those contexts solo car use is still the dominant transport mode. Stated (Murray, 2012; Wright et al., 2018) and revealed preference surveys (Yan et al., 2019), as well as simulations (Stiglic et al., 2018; Yan et al., 2019; Wright et al., 2020) suggesting promising potentials for the integration of carpooling services into MaaS platforms for sub-urban areas have already been performed. Also, route matching algorithms aimed at finding optimal inter-modal trip solutions have been developed (Agatz et al., 2011; Varone and Aissat, 2015; Jamal et al., 2017). However, evidence stemming from real-life implementation is still limited (Cellina et al., 2020; Mitropoulos et al., 2021; Thao et al., 2021; Shen et al., 2021): the practical feasibility of integrating carpooling into MaaS platforms has not been investigated yet. Which practical conditions may hinder the effectiveness of inter-modal MaaS platforms that leverage carpooling?

A process we run in 2022 in the Swiss-based "MixMyRide" research project provides us with useful insights to answer this question. MixMyRide aimed at developing an app-based inter-modal MaaS system combining public transport, micro-mobility (walking, cycling, including shared bicycles, and e-scooters), and dynamic carpooling services. To better meet the needs and desires of prospect MixMyRide users, thus increasing its potential uptake, we run a series of co-design workshops, that helped us to improve the design of the specific MixMyRide's features. The analysis of the elements that emerged during the workshops, however, also allows us to uncover general value challenges, that —beyond the specific case— can negatively affect the practical implementation of MaaS platforms integrating carpooling.

In this article, we present four critical challenges that we identified based on the MixMyRide workshops and advance proposals on how to tackle them, by drawing from both previous literature and ideas by workshop participants themselves. The suggestions we provide offer practical contributions to increase the effectiveness of policy interventions based on inter-modal MaaS platforms aimed at supporting the transition to a less car-dependent mobility system.

2. Material and methods

To address our research question, we analyse insights emerging during the development of the MixMyRide MaaS prototype, followed by a focused, in-depth analysis of closely-related scientific literature in a variety of domains. The whole process is sketched in Fig. 1.

The MixMyRide prototype aimed at creating novel inter-modal mobility solutions to reduce solo car use, by combining public transport, dynamic carpooling, and micro-mobility data via artificial intelligence algorithms to match travel demand and supply. A typical inter-modal trip to be suggested by MixMyRide would for instance consist of a carpooling leg from home to a railway station ("first mile"), then the main leg by train, and then a final leg by foot, shared bicycle, or carpooling again ("last mile"). Namely, MixMyRide considered public transport as the backbone of the mobility system, and saw in carpooling and micro-mobility service the opportunity to amplify public transport networks' coverage and flexibility across urban and sub-urban regions, via the creation of an innovative "Public–Private-People Partnership" (Kuronen et al., 2010).

Apart for its route planning algorithms, that were developed by specialists in Operational Research based on early work by Jamal et al. (2017), MixMyRide's features were developed via a co-design approach in a living lab framework, namely a process to create and validate innovation within collaborative, real-world environments (Almirall et al., 2012; Dell'Era and Landoni, 2014; Pallot et al., 2010), with the involvement of a broad range of stakeholders (Scholl et al., 2018). These approaches, that have a long tradition in innovation in the field of information and communication technologies (Eriksson et al., 2005; Følstad, 2008), are increasingly used to support sustainability transitions in a broad range of domains. They engage users from concept generation to prototype design and then real life testing and evaluation

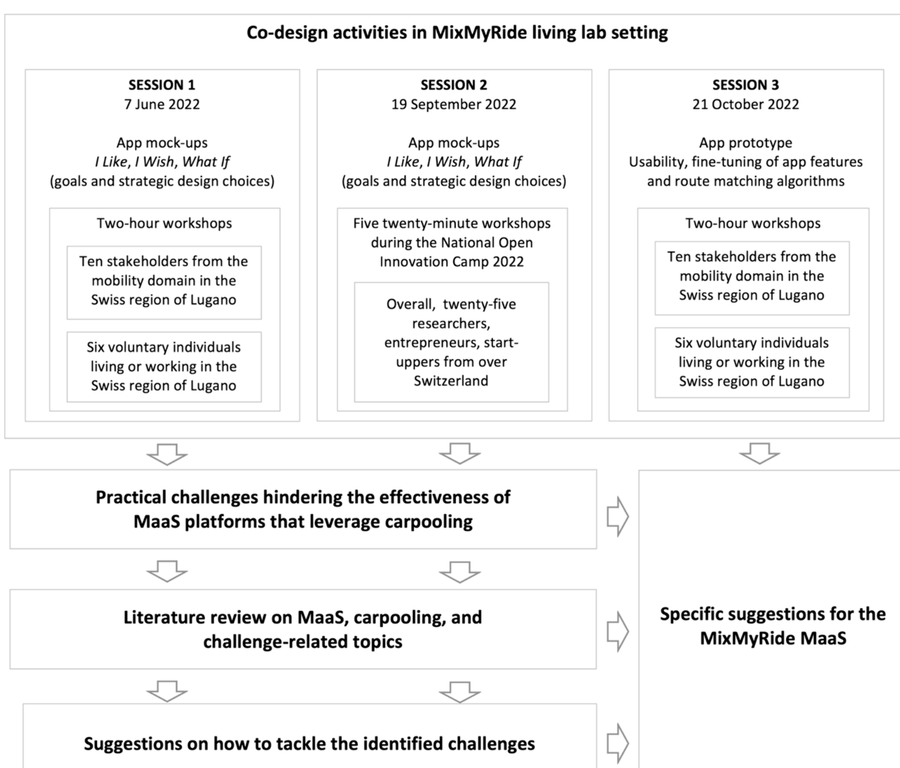

Fig. 1. Overview of the process we followed to address our research question.

(Visser et al., 2005; Bergvall-Kåreborn et al., 2010; Evans and Terrey, 2016). They allow to overcome expert mindsets, where users are seen as "subjects", called to test something someone designed for them, and to open to participatory mindsets, where users are seen as active "partners" of the value creation process (Sanders, 2002; Sanders and Stappers, 2008): instead of "designing for the users", living labs support "designing with the users" (Schuler and Namioka, 1993). They allow novel understandings on phenomena and their possible consequences to emerge and to be shared, thus increasing the designers' capability to create engaging tools and better address the needs and desires by prospect users (Itten et al., 2021).

In the case of MixMyRide, not only the workshop discussions helped us to identify the specific characteristics of the desired MaaS prototype. By bringing together a multiplicity of competences and perspectives, as well as expectations and needs, to emerge, they also allowed us to get a comprehensive understanding of practical factors that can challenge the effectiveness of MaaS platforms integrating carpooling. In some cases, elements from the workshops also supported us in the identification of possible solutions; in others, they only managed to identify the challenge, leaving the responsibility to identify possible solutions to our research team, that was expected to contribute to the co-design process at the same level as the workshop participants. The co-design process was organised around three workshop sessions, which took place between June and October 2022 in the region of Lugano, in the Italian-speaking part of Switzerland (see Fig. 1). In this article we use materials from the first two workshop sessions, that focused on strategic-level characteristics of the MixMyRide MaaS prototype and therefore can offer general-value insights for other MaaS platforms integrating carpooling. The third workshop session instead focused on the usability, user experience, and fine-tuning of the advanced versions of the MixMyRide app features and route matching algorithms. Though highly relevant for the outcomes of the whole MixMyRide co-design process, insights on these topics are out of the scope of this article and therefore we do not refer to them.

In the workshop sessions, the general concept behind the MixMyRide MaaS, namely the desire for a tool capable to integrate public transport, (shared) micro-mobility, and carpooling, was taken as a starting point. The goal was set on how to ensure that such a tool could achieve a sufficiently large number of users, to effectively support the reduction in solo car use. To help raise critical but actionable discussions, we opted for feeding the workshops with wireframe mock-up prototypes of the MixMyRide app, previously drafted by our research team, and for collecting participant feedback on the goals and strategic design choices behind them. In both workshop sessions, the discussion was organised around the three guiding items "I Like, I Wish, What If" typically used in design thinking processes (Doorley et al., 2018). "I Like" elements can be associated with strengths; instead, "I Wish" and 'What If' elements are more closely related with weaknesses and possible practical implementation problems, as they hint at design choices that should have been performed differently, or at elements that the MixMyRide prototype mock-ups had not addressed yet. To address our research question we therefore especially look for insights about the last two elements.

In the first workshop session (7 June 2022), in-depth discussions with a small number of people were performed, while the second session (19 September) engaged more people via less detailed interaction. The first session involved a group of ten selected stakeholders operating in the mobility domain in the region of Lugano (transport operators, cantonal and municipal institutions in the mobility and land development field, start-uppers, environmental non-governmental organisations), identified via an interest/influence stakeholder analysis (Reed et al., 2009), and a group of six voluntary citizens either living or working in the region, that self-selected themselves by responding to social media campaigns offering a 50 euro incentive reward. For both groups, a separate two–hour workshop was organised. In each workshop, activities started with a brief introduction to the MixMyRide goals, followed by a few minutes for individual exploration of the mock-ups and individual reflection. Then, group interaction was stimulated by inviting every participant to summarise their comments and share them via sticky notes on collective posters, that were used as a starting point to activate a plenary, free discussion, during which everyone was invited to add her/his opinion on what the previous person had said.

The second session was instead organised within the broader Swiss-based "National Open Innovation Camp 2022", an annual meeting aimed at showcasing and discussing innovation for the energy transition and the decarbonisation of the economy. The venue, attended by entrepreneurs, start-uppers and researchers in the energy, mobility and digitalisation domains from all over Switzerland, provided the opportunity for five small-group, 20-min co-design workshops engaging a total of twenty-five individuals —again, self-selected. Elements emerging from this session thus complemented the insights we received from the first session, thanks to different professional perspectives and cultural backgrounds of its participants.

During each session, a member of our research team took word-per-word detailed notes (smooth verbatim transcripts) of most of the conversations, though no full meeting recording was performed. The detailed notes collected by the research team members during the two workshop sessions were merged and then coded in categories, according to a qualitative content analysis approach (Mayring et al., 2004). Despite the researchers that performed the coding were informed by preliminary knowledge of the scientific literature on carpooling and MaaS systems, the categories were not pre-defined and were created and refined during the analysis as long as new elements were emerging, according to an explorative, inductive approach (Mayring et al., 2019).

Through this process, we identified key practical challenges that, from the perspective of workshop participants, can tangibly hinder the effectiveness of MaaS systems aimed at integrating carpooling with public transport and micro-mobility services. Starting from such challenges, in the following months our research team performed an in-depth and focused exploration of the scientific literature about closely-related topics, drawing from different disciplinary domains. We used the challenge categories that resulted from the coding process as keywords for search in the Google Scholar scientific data-base, accompanied by the following general keyword list: *MaaS*, *Mobility-as-a-Service*, *carpooling* (including *car pooling* and *car-pooling*), *inter-modal**, *multi-modal**, *sharing mobility*, *micro mobility*, and *active mobility*. Starting from the resulting materials, we further explored related relevant articles, as typically performed in narrative style literature reviews. The analysis of the resulting material allowed us to identify and discuss possible ways to tackle the challenges, which we describe in this article by again adopting a narrative style. In some cases, the discussion in the workshops also helped to advance possible solutions on how to overcome the challenges that were identified. In such cases, our in-depth exploration of the related scientific literature allowed us to either confirm and enrich those solutions with insights from previous initiatives, or to reject them and look for alternative solutions, due to the identification of shortcomings. In the next section we summarize the outcome of the whole process, by presenting the challenges we identified and extensively discussing our proposals for challenge solutions, based on our learnings from the co-design sessions and findings by previous literature.

3. Results and discussion

The topics that we identified based on the discussion during the first and second co-design sessions are reported in Fig. 2. Overall, N = 167 different elements emerged, which we coded in six aggregate-level and eighteen detailed-level topics. About half of the elements (n = 85), were specifically related with the characteristics of the MixMyRide prototype and the way its features were tentatively implemented by the research team in the mock-ups that were shown to stimulate and raise discussion. Since those elements are very specific to the MixMyRide mock-up prototype, they cannot provide general-value insights and therefore here we do not explore them further. Among the other half of the elements, a few

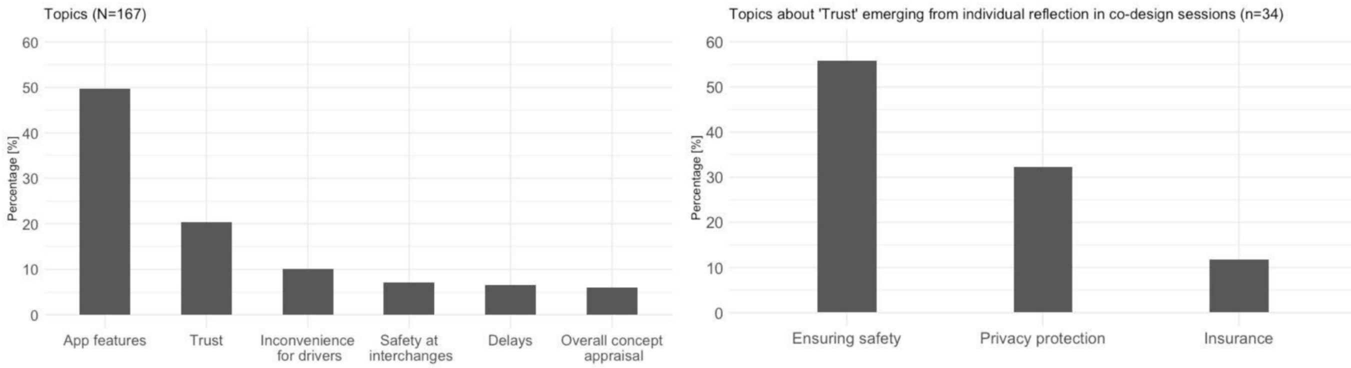

Fig. 2. Challenges emerging from individual reflection in the first two co-design sessions. On the right, details about the "Trust" topic, classified in sub-topics.

(n = 10) consisted in general appraisals of the concept underlying the MixMyRide app. The remaining elements (n = 72) are instead worth further investigation, as they dealt with challenges of practical interest for any MaaS system aiming at integrating carpooling services.

We classified such elements in four general-level challenges, that lie at the crossroads between carpooling, transport infrastructure development, and digital big data: higher risk of being affected by traffic perturbation and delays, lack of trust between MaaS users, traffic safety problems at inter-changes, and need for incentives to overcome inconvenience for drivers and ensure carpooling rides are offered. For MaaS platforms integrating carpooling to deliver the expected benefits to the mobility system via reduction in solo car use, all these challenges have to be properly addressed. In the next sections we present and discuss each of them in a narrative style: by referring to both elements emerging from the group discussions in the co-design sessions and related findings by previous literature, we advance our proposals about how to best tackle them.

3.1. Higher risk of being affected by delays

Adding an additional mobility option like carpooling increases the set of mobility services available within a MaaS system, thus allowing higher trip matching possibilities (Wright et al., 2020). This is exactly why MaaS-enabled inter-modal combinations of public transport, (shared) micro-mobility and carpooling services can become viable alternatives to solo car use for low-density sub-urban regions. However, leveraging such combinations also entails the increase in the number of transport mode inter-changes in the same trip, which makes the overall trip solution more vulnerable and prone to the risk of trip chain disruption due to delays in public transport legs and road traffic perturbation. Workshop participants were particularly worried by delays affecting route solutions that involve carpooling legs: *How do you deal with delays that may preclude inter-change options? How do you manage information to and interaction between rider and driver?* [Representative of car driver association, man].

As small public transport delays and longer than average carpooling travel times can result in missing tight inter-change connections, the optimal trip solutions identified by MaaS route planning algorithms might actually not stand their real-life implementation. To limit such problems, larger interchange times could be considered by the MaaS route planning algorithms. This would however reduce the appeal of the MaaS trip solutions, reducing the chances that they are welcomed as alternatives to solo car driving. A better approach could consist in feeding the MaaS algorithms with predictable time-dependent travel time estimates, namely travel time estimates that account for average travel times previously registered in the same day of the week and time of the day as the searched trip (Ichoua et al., 2003; Fleischmann et al., 2004; Haghani and Jung, 2005). Historical series of mobile big data can for instance be collected by mobile network operators, that can massively and passively track people's position by identifying the location of their smartphone in the cellular network, especially when they are making a phone call (Chen et al., 2016; Zhao et al., 2016; Cheng et al., 2017). This data is for instance now routinely offered by location services such as those provided by Google for a fee, which are already used by MixMyRide to estimate road traffic travel times. To our knowledge, however, such a piece of information is rarely available for public transport services, for which at best real-time data is available in small data-sets (Welch and Widita, 2019) and schedule data is frequently the only available information. Long historical series of real-time public transport data would be needed as well, to ensure that time-dependent travel times can be computed along the whole inter-modal mobility chain and be used to feed the route planning algorithms.

Despite these expedients, unpredictable disruptions that go beyond average travel times may always occur. Additional features are therefore needed to ensure that travellers can still complete their trips also in such cases. Re-scheduling real-time information systems for public transport services have for instance been developed by Bruglieri et al. (2015) or Lai and Leung (2018). For inter-modal mobility, when a planned trip is about to start (e.g. 30 min or 15 min before a scheduled trip start), MaaS systems could automatically check and verify the updated, real-time travel times, and provide users with push notifications in case they find any disruptions with respect to the scheduled trip. In such cases, the MaaS platform could also automatically invoke the route planning algorithms to identify novel trip solutions based on the available real-time data. Then, such solutions would be automatically suggested to MaaS users via push notifications.

If the disrupted trips include carpooling legs that are no longer compatible with the delay situation, push notifications would also be automatically sent to both carpooling drivers and riders, to cancel previously agreed upon rides. Ideally, advanced systems should also be able to send vocal notifications, particularly to carpooling drivers, who might already be travelling and therefore be unable to access text push notifications on their smartphone. For MixMyRide, for instance, algorithms capable to detect changes with respect to planned trip solutions have been developed. However, they could not be implemented, due to the lack of high granularity public transport and road traffic real time data needed to feed them (Derboni et al., 2018). Overall, without significant investments in technologies to collect real-time transport data and make it automatically accessible[1], the challenge of delays and traffic disruption will remain open.

Until such data are available, if trip solutions include carpooling legs that, due to delays, can no longer be performed as planned, in-app

[1] Preferably under open-access licences, such as for instance the "sharedmobility.ch" webportal created by the Swiss Federal Office of Energy, that reports real-time data on the use of shared mobility services throughout Switzerland (https://github.com/SFOE/sharedmobility, last accessed on 4 September 2023).

features for quick interaction between MaaS users (e.g. drivers and riders) become essential. This requires the availability of internal messaging systems (chats), that allow the carpooling companions to revisit their plans and agree on different trip arrangements: *Without an internal chat, whenever we arrange a carpooling ride with another person, the MaaS should make our phone numbers visible to each other, to ensure we can call or text if any problems or delays occur. I would not appreciate my phone number is publicly shown. Also, relying on external apps such as Whatsapp or Telegram, would imply we save the phone numbers in our contact list, in a way that we can retrieve them if needed when delays occur. To be honest, I don't think I would accept this effort. An internal chat is really a compulsory feature for a MaaS wishing to integrate carpooling* [Citizen, woman]. Carpooling drivers are not as strictly constrained to respecting time schedules as public transport. Therefore, we cannot exclude that, under disruption, some carpooling rides can be maintained, provided that both the driver and the rider have sufficient flexibility to re-arrange their plans and wait for the companion to reach the planned inter-change point. The presence of an in-app chat can help ensure that re-arrangements are taken swiftly, provided that carpoolers can access it very close to the scheduled trip, or even during the trip itself —which however is not always the case for drivers. Managing to automatically deal with technology-enabled trip re-scheduling processes would therefore be the most effective way to reassure MaaS users that they will always find a way to perform their trip, even if delays occur.

3.2. Lack of trust between MaaS users

In dynamic carpooling systems like those integrated in MaaS platforms, peer control is lower than in closed-community carpooling such as corporate carpooling, where carpoolers are connected by other types of relationships besides sharing a ride —relationships that existed before and will continue to exist after the ride, such as those between colleagues working for the same company. Dynamic carpooling, in fact, focuses on single, non-recurring trips. Potentially, carpooling drivers that offer rides along their usual commute route might engage with many different carpooling riders. The problem therefore arises about how to ensure trust between strangers, that have no information about each other apart for what is offered by the MaaS platform itself.

This is a well-known problem in the literature dealing with casual or impromptu carpooling (Chaube et al., 2010; Correia and Viegas, 2011; Mote and Whitestone, 2011; Chan and Shaheen, 2012; Furuhata et al., 2013; Créno and Cahour, 2014; Amirkiaee and Evangelopoulos, 2018; Adelé and Dionisio, 2020). While the choice to carpool is usually made by those who value social capital and the desire to socialise (DeLoach and Tiemann, 2012), the need for forced interaction with a stranger in the private space of the driver's car is acknowledged as one of the key reasons why individuals prefer to stick to solo car driving rather than carpool. Discussions in the co-design sessions clearly indicated that many people would not feel at ease in sharing a car ride with a stranger —especially, female riders travelling after dark— and remarked that MaaS platforms should necessarily include features aimed at building trust within the community of their users.

Initially, co-design participants suggested to add an "S.O.S." button into the app, in order to launch alarms and immediately activate geo-localisation features. This proposal was however discarded during the following discussion, when one of the participants noted: *I would not use an app with such a button: instead of making me feel safer, it would make me doubt the carpooling rides may be dangerous* [Representative of environmental NGO, woman]. Following such a comment, participants then suggested that, rather than addressing dangerous situations if and once they take place, MaaS platforms should prevent them to take place. For this purpose, they suggested the app to be equipped with an internal peer-based feedback mechanism, that, for each MaaS trip that includes carpooling legs, invites both the rider and the driver to leave a review of the travel companion as soon as the trip has ended.

Indeed, such review and rating mechanisms aimed at building a user's reputation (Resnick et al., 2000; Dellarocas, 2003; Jøsang et al., 2007) are now widespread in online shopping and service provision platforms, including those based on the sharing economy principles and those offering carpooling services alike. They are usually implemented by simple overall judgments, such as a star-based review system, accompanied by brief texts. To ensure reviews are left, the MaaS platform could send push notifications to both car rider and driver. If in-app payment tools are available to regulate sharing of travel expenses between the car rider and driver, the platform could even release the payment from the driver to the rider only once both have evaluated each other. This would not be sufficient, however, to fully build trust, as this procedure would not allow to deal with novel users that received no or very few reviews and have not built their reputation yet.

Co-design participants indicated they would feel safer (and would thus take the risk to share rides with strangers) if at app registration full personal details, including email address, phone number and personal identity card, were requested and checked by an individual person entitled by the MaaS platform, either in-person or via a live online meeting. Such a check of the digital identity by MaaS users would follow "Know Your Customer" (KYC) standardised procedures typically used by banks to verify the identity of potential customers and avoid money laundering, terrorism financing, or other forms of identity fraud. Activating such procedures would however lead to a direct monetary cost, in terms of the operators that are required to certify potential users' identity, and also another direct, non-monetary cost, in terms of possible drop-out by prospect MaaS users before their registration has been completed and fully verified. A possible trade-off to reduce the risk of drop-out, while still ensuring in-depth checks of app users' identity, could consist in allowing users to register on the MaaS platform by only providing a limited set of personal data, and to require the full KYC procedure to be completed in order for them to perform their first carpooling trip, either as a driver or a rider. Namely, before KYC completion and approval, booking of carpooling rides and agreements between rider and driver would not be allowed.

In any case, even strict procedures aimed at checking the users' digital identity would fail, if bad-minded people really want to cheat the system. A certain degree of perception of lack of safety could therefore remain: *If something bad happens —let's say— to my daughter…I would not be relieved to know the identity of the person that hurt her* [Man, citizen]. In order to keep this perception low, we posit that action on the social and cultural context, well beyond the MaaS users, is needed. Starting from the niche of initial MaaS users, a "normalisation" of carpooling practices would first of all stem from the increase in the number of users, and then spontaneously occur as long as the system achieves a critical mass of users. Specific measures aimed at supporting such a process could leverage descriptive social norms, namely the fact that "the perception of what most others are doing influences subjects to behave similarly" (Cialdini et al., 1990, p. 1015). For instance, research by Bachmann et al. (2018) confirmed that people have higher intentions to carpool if they believe other people are carpooling. Therefore, the authors suggest to "make carpoolers visible", by putting a sticker on their vehicle that signals their carpooling practice to others. Also, they suggest carpooling platform operators to publicly communicate statistics on the evolution of their —increasing over time— user number. Moreover, social norms regarding carpooling could be additionally activated by leveraging social media (Aguiléra and Pigalle, 2021). Inspiration could also be taken from social modelling initiatives that are frequently used for marketing purposes and aim at demonstrating how other people (possibly well-known testimonials) personally engage with a certain behaviour and manage to implement it. These initiatives have proven successful in promoting pro-environmental behaviour in a range of domains (Osbaldiston and Schott, 2012) and therefore may also be effective in supporting the normalisation of carpooling practices.

3.3. Traffic safety problems at inter-changes

The act of inter-changing from a transport mode to the next one is crucial for the success of inter-modal MaaS platforms. Users expect easy and safe inter-changes also when carpooling rides are involved: *How are carpooling inter-changes arranged? Is the driver allowed to stop in any place? And can the rider wait for a ride in a safe place?* [Representative of the cantonal transport department, man].

However, managing to meet these expectations in practice is not trivial. In order to enhance the time-effectiveness of inter-changes between the transport modes involved in the same trip, seamless inter-changes should ideally occur at public transport stops, where shared micro-mobility stations are usually also located. This means that carpooling pick-up and drop-off should also occur at public transport stops. When the inter-change is at the railway or bus station, safe "kiss-and-ride" areas (Schank, 2002) for carpooling pick-up/drop-off are usually available —though they might require carpooling drivers to perform minor detours with respect to their original route. In countries such as Switzerland, in particular, specific plans and programmes by federal offices responsible for transport and land planning are currently active. They aim at improving the effectiveness of "mobility hub" infrastructures in such stations, to ensure seamless, time-efficient, barrier-free, and enjoyable inter-changes between transport modes (Kommission Schieneninfrastruktur, 2023). Similar projects specifically focusing on "shared mobility hubs" are also currently promoted in large stations in other Western countries (Conticelli et al., 2021; Arnold et al., 2023; Roukouni et al., 2023).

Inter-changes at single bus or tram stops can instead become more critical, as infrastructures devoted to this purpose are lacking, and temporary car stops for pick-up or drop-off might create conflicts with the existing public transport network: *I would totally exclude that cars can stop in one of our bus stops* [Representative of the local public transport company, man]. Indeed, in many countries, road regulations explicitly prohibit cars from stopping at bus or tram stops, as it could negatively interfere with public transport time-schedules and create risks for passengers' safety. In Switzerland, cars can stop in areas within 10 meters from bus stop signals, though this is only allowed for very quick pick-up and drop-off: slightly longer —though temporary— stops are not allowed (article 18 of the Ordinance on traffic flow). This would require inter-change times to be always completely optimised, which cannot always be guaranteed. Due to the variability of traffic conditions, in fact, carpooling drivers might happen to reach the pick-up place earlier than planned, and thus have to wait for the riders' arrival.

This problem would be solved if the MaaS platform could only consider interchange spots that are sufficiently close to actual interchange points and at the same time are suitable for safe temporary parking. However, current MaaS route planning algorithms lack the capability to identify such spots. Thus, maps of the potentially suitable areas for inter-change should be created on a prior basis and then provided as an input to the route planning algorithms. To our knowledge, however, such maps are currently nowhere available, and their on-purpose development would require significant time and money investment, which MaaS platforms would unlikely be able to bear. Therefore, despite huge progress in artificial intelligence, the drivers' or riders' personal knowledge of the inter-change area —or their capability to interact with an online map representing it— is currently still needed.

In order to ensure that carpooling pick-ups and drop-offs are safely performed, carpooling companions thus need to invest some time in identifying the proper inter-change places and agree on them, by means of a few chat-based interactions. Though this is quite an easy task (especially considering that drivers most likely offer carpooling rides for routes they frequently travel, such as their commuting trip, for which they know the route and its surroundings quite well), such a need for arrangements adds inconvenience and requires in-advance trip planning, negatively affecting the MaaS's promise of highly dynamic and real-time travel. Particularly, the added inconvenience could be sufficient to discourage prospect carpooling drivers from offering carpooling rides via the MaaS platform.

3.4. Need for incentives to ensure carpooling ride offer

The key benefits stemming from the integration of public transport, (shared) micro-mobility and carpooling in MaaS services like MixMyRide lie on the availability of offered carpooling rides, which enables to enlarge the amount of connections already made available by the existing public transport and (shared) micro-mobility networks. Therefore, the possibility to enjoy such benefits largely depends on the availability of carpooling rides, that are voluntarily offered by individuals for other individuals. Simulations have shown that, compared to carpooling alone, a much lower number of offered carpooling rides is needed in order to find suitable trip matches when carpooling is combined with public transport (Wright et al., 2020). However, a critical mass of offered carpooling rides is still necessary (Cairns et al., 2010; Montero, 2019): the larger the region to be covered by the MaaS, the larger the need for offered rides.

Indeed, this is far from granted. Why should drivers accept possible discomfort and risks (Correia and Viegas, 2011), emotionally demanding interactions and forced sociability due to sharing of personal space with strangers (Adelé and Dionisio, 2020), minor deviations from their usual routes (Chapron et al., 2013), and a perceived loss in their flexibility and independence (Li et al., 2007), and make the effort to enter their trips in advance into a MaaS platform? Previous research has clearly shown that the user experience in traditional carpooling systems is affected by a number of barriers, which require targeted incentives for both drivers and riders, such as reducing travel or parking costs, decreasing travel time through reduced congestion, increasing travel pleasure through social interactions, accessing carpooling-only lanes, or being rewarded for one's contribution to the environment and climate protection (Chaube et al., 2010; Abrahamse and Keall, 2012; Chan and Shaheen, 2012; DeLoach and Tiemann, 2012; Créno, 2016; Delhomme and Gheorghiu, 2016; Amirkiaee and Evangelopoulos, 2018; Bachmann et al., 2018; Neoh et al., 2018; Adelé and Dionisio, 2020; Bulteau et al., 2021; Shen et al., 2021).

Specifically regarding car drivers, previous research has shown that some car drivers are more open than others to offer rides, depending on their desire for socialising (DeLoach and Tiemann, 2012). In general, however, solo car drivers were found to be more likely to switch to carpooling as drivers rather than passengers, since doing so they would not need to change their car-driving practices (Le Goff et al., 2022). These findings would therefore suggest that incentives are mostly needed for solo car drivers to become carpooling riders. However, we argue that, when dynamic carpooling is integrated into MaaS platforms, specific incentives are generally also needed to stimulate car drivers to offer rides. Such a carpooling approach is in fact more challenging than the most widespread forms of planned carpooling (e.g. coworker carpool), that are usually characterised by relatively stable arrangements and teams, made of individuals with either pre-existing relationships or whose relationships get easily shaped by the daily repetition of the carpooling ride. In such cases, carpooling companions tend to regularly commute by car together, by alternating in driving their own car. If so, the incentive is immediate, consisting in the reciprocity and the possibility to halve one's commuting car use and the consequent costs, emissions, and stress factors. In the case of dynamic carpooling, in which rides may potentially be shared with always different companions, such an incentivising condition does not occur, and on-purpose incentives for car drivers need to be introduced. One of the MixMyRide co-design participants was very explicit about such a need: *Why should I share a ride in my car? What is the reward? What are the benefits I would enjoy for sharing?* [Researcher in the domain of energy transition, woman].

In the region of Washington DC, more than a decade ago impromptu casual carpooling ("slugging") was strongly incentivised by regulations allowing access to certain highway lanes only to cars with three or more passengers ("high-occupancy vehicle" lanes, HOV). In such a case, the time savings stemming from access to HOV lanes were sufficient to induce car drivers to offer rides to unknown people, that simply queued at HOV collection points, waiting for a ride (Li et al., 2007; Mote and Whitestone, 2011; Chan and Shaheen, 2012). When comparable regulations cannot be introduced due to a lack of available lanes to only devote to carpoolers, potential carpooling drivers need to find other specific benefits for offering carpooling rides.

Sharing of travel expenses between the driver and the rider is the strategy usually exploited by carpooling platforms offering long-distance trips (Saxena et al., 2020; Yeung and Zhu, 2022), which was already attempted in carpooling initiatives at the urban level: the rider pays an agreed upon fee to the driver, based on a pay per use approach, for instance by using a flat rate per travel kilometer suggested by the MaaS platform itself. Previous research has extensively explored the effectiveness of monetary incentives in carpooling initiatives, showing that they are effective, though the effect size tends to be small. For instance, Amirkiaee and Evangelopoulos (2018) have found that economic benefits have positive, but weak, effects on attitudes towards carpooling and the consequent intention to carpool, both as riders or as drivers. Similarly, a meta-analysis of 22 empirical carpooling studies has shown that saving money has small influence on choosing carpooling, both for riders and drivers (Neoh et al., 2017). Bulteau et al. (2021) have also shown that financial incentives are necessary, but not sufficient, motivation for carpooling: they should be combined with psychological incentives (e.g. knowing the carpooling companion) in order to promote carpooling successfully. Recent research by Shen et al. (2021) specifically about the integration between public transport and carpooling in the US, has shown that monetary incentives targeting both carpooling drivers and riders are indeed effective in increasing the adoption of carpooling services, however the effect size varies on user sub-group characteristics and it is higher with individuals younger than 45 years old. And research by Tahmasseby et al. (2016), that specifically differentiates between carpooling drivers and riders, has found that monetary contributions to drivers are only marginally significant in influencing their decision to offer rides.

Based on the above findings, "sharing of expenses" incentives appear to be a necessary condition for car drivers to offer carpooling rides. Further research might help to specifically clarify whether they can also act as a sufficient condition for car drivers to offer rides, in the broader framework of carpooling integrated into MaaS services. The perception by participants to the MixMyRide co-design workshops is that they act as a necessary, but not sufficient condition. Participants suggested that, in addition to sharing of travel expenses, also reward vouchers are offered by public institutions, similarly to policy subsidies that are usually attributed to public transport to cover its deficit performances (e.g. each offered ride or travel kilometer corresponds to a certain amount of earned money). Also, they suggested that virtual, non-tangible rewards are offered by means of gamification approaches (Olszewski et al., 2018; Tripathy et al., 2020; Wang et al., 2022). For instance, such rewards could consist in virtual badges offered to the drivers when they reach a given threshold, or are better than other MaaS users in a ranking, for instance based on the number of offered rides, on saved global CO_2 emissions, or even on the novel socialisation opportunities they benefitted from.

Even though the goal should be for a service that in the long-term can self-sustain itself, co-design participants therefore suggested that additional supporting measures are needed, at least at the launch of the MaaS service, to reach a sufficiently large, critical mass of users that offer carpooling rides. Besides "sharing of expenses" monetary incentives, additional measures supporting MaaS users in offering carpooling rides could aim at "making their life easier", by reducing the effort they are requested to perform, once they have offered a ride, a carpooling match has been found, and a carpooling agreement has been made. For instance, participants to MixMyRide co-design workshops suggested to go beyond just sending push notifications to remind drivers about a scheduled carpooling ride, and to create automatic connections between the MaaS app and the digital calendar and GPS navigation apps already installed on the user's smartphone. *Push notifications are not enough. I would like a step-by-step guide to appear in my calendar: leave the office at time X, go to road Y, then wait for Ms. Smith, and then bring her to road Z, etc.* [Start-upper, man]. Furthermore, trip navigation features could be automatically activated just before the scheduled time for the carpooling ride, guiding the driver throughout the whole trip and to the rider's pick-up and drop-off places.

The discussion in the co-design sessions highlighted, however, that the real-life implementation of sharing of expenses approaches into MaaS platforms may be affected by additional open challenges, which are important to remark. First, ensuring that sharing of expenses takes place requires specific "virtual wallet" in-app features capable to transparently manage the transactions between the users and to reassure them that no cheating takes place. Guaranteeing that money transactions are safe, reliable, and up to money transfer standards can thus be technically demanding and require significant costs for MaaS developers and managers, especially for small-scale MaaS platforms. Second (and definitely more relevant, as it may preclude achievement of a critical mass of users), in inter-modal trips enabled by MaaS platforms, the expenses riders would cover for their carpooling legs would need to be added to the expenses for their other trip legs by public transport and/or shared micro-mobility. Pricing schemes for the latter however usually depend on travel time within a given region, rather than on the specific trip route, and already allow for unlimited use of different public transport modes and/or routes, within that region and a given time interval. MaaS users might therefore not be willing to pay for additional money to the tariffs, already in place, that allow them to travel by public transport and/or shared micro-mobility in a given region. There is thus the risk that riders perceive overall inter-modal trip costs as too high. If so, the incentive for drivers risks to turn into a disincentive for riders.

By drawing on a survey of about two hundred individuals, Tahmasseby et al. (2016) found presence of such a phenomenon. However, there is still a lack of clarity whether specific MaaS pricing schemes can be adopted to avoid triggering such a disincentive. The majority of MaaS platforms in fact aim at offering "one-stop-shop" subscription-based payment systems, that allow access to a bundle of mobility services by different transport operators with the convenience of a single interaction for payment, on a weekly, monthly or annual basis. A few choice experiments based on stated-preference surveys have been performed to identify which subscription-based payment models, together with the related amount of money, would be more acceptable by potential MaaS users (Matyas and Kamargianni, 2019; Caiati et al., 2020). However, for the time being only a small number of real-life MaaS initiatives managed to practically implement such integrated subscription systems; rather, most of them still rely on payment systems that separately deal with each of the transport service providers they include, in a pay-as-you-go model (Caiati et al., 2020; Wolking and Trölsch, 2023): users pay for each trip leg based on the prices set by each transport service operator. Achieving tariff and pricing integrations that not only includes public transport and shared micro-mobility operators, but also carpooling operators (as intermediaries for all the drivers offering rides), would require to attain complex institutional agreements between public agencies and private actors dealing with the transport sector, which many public agencies are not yet open to or willing to activate (Chan and Shaheen, 2012; Wolking and Trölsch, 2023). Until such agreements are taken, only choice experiments can be used to identify which MaaS pricing schemes for carpooling legs could minimise possible disincentives for riders to use MaaS platforms that integrate carpooling services.

4. Conclusions

In this paper we have identified four practical challenges potentially hindering the effectiveness of Mobility-as-a-Service (MaaS) platforms that integrate public transport, (shared) micro-mobility and carpooling services. Such challenges were identified via co-design activities we performed in Southern Switzerland in late 2022, during the development of MixMyRide, an inter-modal app-based MaaS prototype within a research project. Simulations performed in previous research have in fact shown that the integration of carpooling in MaaS platforms has promising potential to reduce solo car use. Knowledge about how such a potential can be practically exploited, however, is still missing; particularly, it is not clear yet whether and how practical challenges can negatively affect the success of such MaaS platforms. Our findings therefore contribute to fill this research gap. Furthermore, drawing from previous literature on carpooling, inter-modal mobility, and Mobility-as-a-Service, we have also provided general-value suggestions on how to address such challenges, which could be useful for other MaaS platforms aiming at integrating carpooling services. The challenges and our suggestions can be summarised as follows.

First, including carpooling legs in inter-modal travel solutions increases vulnerability to traffic perturbation and delays, which reduces the robustness of the mobility solutions identified by the MaaS platform, compared to solo car use. To increase the solutions' robustness, long historical series of high granularity, real-time traffic data are needed for both private and public transport, to feed the MaaS route planning algorithms. Such a need calls for specific policy interventions aimed at increasing digital innovation in the mobility sector and at supporting open accessibility for the collected mobility data. In both cases, these measures need to be performed by other actors than the MaaS developers. Second, MaaS platforms need to find simple ways to build trust between their users, for example by ensuring that users' real-life identity is transparently and reliably collected in a low-effort and non-intrusive way. Third, ideal inter-changes between carpooling and other transport modes coincide with public transport stops. However, bus and tram stops can rarely be used for this purpose, as this might critically interfere with public transport's schedule and affect traffic safety. Public transport infrastructures would therefore require to be largely re-designed with respect to today, to favour seamless and safe inter-change with carpooling. Currently, however, carpooling companions need to make prior arrangements about the most convenient places for pick-up and drop-off, which requires time, affects the dynamism of the whole system, and causes inconvenience to both carpooling riders and drivers. This brings us to the last key challenge, namely the need for incentives to ensure carpooling rides are offered. Without offered carpooling rides, the potential stemming from the inclusion of carpooling services would only be theoretical and therefore useless. This challenge does not affect systematic carpooling schemes that leverage regular commuting teams and the opportunity to halve costs, stress, and emissions by alternating driving with a travel companion, or casual carpooling teams that are built on the spot in order to access high occupancy vehicle lanes. Rather, it has already emerged in long-distance and dynamic carpooling platforms. To ensure that carpooling rides are offered necessarily calls for sharing of expenses between riders and drivers and possibly also for additional monetary incentives covered by public institutions. Gamification approaches providing virtual rewards could also be attempted. Evidence on the effectiveness of such incentives should be gathered by future experimental research performed in real-life conditions.

The insights we have collected from the MixMyRide co-design workshops, that informed our following literature analysis and proposals of solutions about to tackle them, might be affected by a number of limitations. Even though the stakeholder and citizen groups that participated in the co-design sessions were largely diverse and our analyses also include the contributions by the Swiss-wide innovators joining the National Open Innovation Camp 2022, the set of challenges we identified may still be influenced by the Southern-Switzerland infrastructural and cultural conditions in which they operate. Also, it may be influenced by the fact that they self-selected themselves to join the co-design workshop activities. Furthermore, they were a small number of people, invited to deal with a prospect MaaS tool, rather than to directly interact with it under their real-life daily needs, expectations, and constraints. Our research team could thus only access their reported perceptions and stated preferences, rather than observe their actual behaviour in real-life. To complement our findings with quantitative analysis as well as to address the representativeness and self-selection issue, choice experiments based on larger and more representative samples might be a relevant avenue for future research. In addition, future research should provide evidence on the real-life effectiveness of the suggestions we have proposed to tackle the challenges we have identified. Finally, quantitative and qualitative analysis of the type and amount of interactions with the MixMyRide app that was finally implemented and that at the time of writing (Winter 2023) is being field tested in the three Swiss regions of Geneva, Winterthur-Zurich, and Lugano, will certainly be helpful to integrate and enrich the lessons we have drawn from the co-design workshop sessions and the following literature analyses. Nevertheless, more scientific evidence on real-life experimentation is definitely needed in the future, to clarify whether and to which extent the integration of carpooling in MaaS platform is actually beneficial to the transition to a more sustainable mobility.

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