MaaS for the suburban market: Incorporating carpooling in the mix.

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Abstract

Mobility as a Service (MaaS) is often cited as providing an alternative solution to car ownership and car dominated lifestyles. However, MaaS as it currently exists appears to cater mainly for a specific segment of society – those who live close enough to walk to good quality public transport for daily journeys and close enough to access car share/car rental for other trips which public transport cannot serve. By default, this is limited to large, dense urban areas. This paper considers the evolution of intermodal journey planning that incorporates carpooling with public transport in the transition towards MaaS for suburban areas. It introduces a new journey planning App (known as *RideMyRoute*) that allows users to discover and make connected journeys involving carpooling and public transport, presenting key aspects of its design, development and testing.

Results from a trial of the *RideMyRoute* App in four European test sites (Canton Ticino, Brussels, Zagreb and Ljubljana) revealed that the App was able to suggest trip planning solutions which included carpool options for one in five journey planning solutions and that the majority (85%) of these were solutions that involved connection from carpool to public transport. This is a significant advance on what is currently available through existing carpool provider systems or journey planning apps/services and could potentially increase the attractiveness of MaaS options in suburban markets. However, quality of data feeding the App from external sources remained an issue, as it is with all MaaS systems, and recommendations for future practice are presented. In conclusion, the new intermodal trip planning algorithm and data structure supporting it provide a fundamental stepping stone towards incorporating carpool services within MaaS-type offerings in the future.

1. Introduction

Over the last few years the Mobility as a Service (MaaS) concept has generated much interest within the mobility sector across the world, although as Mulley (2017) notes there is still no single definition of MaaS. All definitions emphasise the service nature of mobility in contrast to mobility coming from an owned physical asset such as a car (see for example Transport Systems Catapult, 2016). Technology is a critical enabler of MaaS, which can be seen as a technology-enabled Mobility Management service (Mulley, 2017); this is a useful observation since Mobility Management is a long-established and relatively well understood concept.

A review of the literature (Mulley et al, 2018) suggests that in addition to technology as an enabler, the key drivers affecting a successful implementation of MaaS are likely to be: widespread availability of modern digital solutions making the demand and delivery of mobility options possible in time windows which previously would not be possible; access to open data (e.g. timetables, real-time location information, user-generated content); provision of interoperable payment systems of transport service providers (e.g., railway operators, taxis, local transport operators, car sharing); regulatory reform to accommodate mixed-mode opportunities; and the ability to provide scalable solutions. In essence, MaaS is built around providing multiple travel options to users through providing information on these options and making their use as simple as possible. The backbone of the service offer is public transport, with the other service modes providing alternatives to public transport for certain trips where this is more appropriate or convenient.

A review of experience shows that the development and deployment of MaaS systems initially in several European cities (e.g. Helsinki, Gothenburg, Lyon, Berlin) are being followed with plans for development in cities in North America and Australia (see Jittrapirom et al (2017) for a recent review of a number of MaaS operational and pilot schemes). The MaaS-type services which have been deployed in European cities to date typically share similar characteristics:

- They are located in large cities that have extensive and well-established public transport services, often combined with high levels of traffic congestion and high cost/limited parking. Use of public transport during peak periods for the journey to work is already 50% or more in many of these cities[1] while use of the car for the journey to work is typically below 25%. Car ownership also tends to be much lower than national averages.
- They focus on integration of public transport with a limited set of shared transport services used on an individual basis. Of the 15 MaaS-type services reviewed by Kamargianni et al (2016), each integrates public transport services with car sharing (in all cases), car rental (in all but 3 cases), bike sharing (in all but 2 cases) and taxi (in all but 3 cases).

It would thus seem that MaaS, as it currently exists, appears to cater mainly for a specific segment of society – those who live close enough to walk to good quality public transport for daily journeys and close enough to access car share/car rental for other trips which public transport cannot serve. By default this is limited to large, dense urban areas.

One form of shared transport, not previously integrated in MaaS systems, which can potentially provide access to the public transport network is carpooling. While the integration of carpooling as an additional mode in MaaS offerings may provide some limited benefits to users in urban areas, the greatest potential comes in suburban areas where car ownership and use is much higher because alternatives for accessing the public transport network are much more limited: distances to access the public transport network are longer, so walking and cycling are not feasible options for many (and may not be supported by suitable infrastructure), taxi use is unsuitable for most routine journeys due to cost and population density does not support commercial new mobility services. Incorporating carpooling connections to public transport within a MaaS system can potentially result in dramatic increases in collective travel options in suburban areas thus enhancing the contribution of MaaS to sustainable mobility.

When carpooling is considered as a feeder for first and last mile connections to public transport, the problem of needing to match origin, destination (or points along the route between origin and destination) and time of travel is relaxed since carpooling only needs to be able to provide the connection to/from suitable stops on the public transport network. This effectively changes the problem from a one-to-one matching to a one-to-many or many-to-one matching problem. As a result, the density of trip offering required is much lower (offer to request ratio is much lower) and so the

[1] For example, the average share of people using public transport as their principal means of getting to work in the 72 largest and capital EU cities was 49.3 %. Shares of 60 % or more are found in the capital cities of 10 European countries as well as in Barcelona. The national average share of people using public transport for the work commute in towns and suburbs is typically below 15% and often below 10% (Eurostat, 2016).

possibility of finding carpool options is dramatically increased in lower density suburban environments.

The research questions which this paper seeks to address are how can information on carpooling be incorporated within a MaaS-type system; the extent to which this increases carpool matches/possibilities; and whether there is an appetite from suburban commuters for this type of offering. To achieve this, the paper considers the evolution of intermodal journey planning that incorporates carpooling with public transport as a means to increase attractiveness of MaaS options in suburban areas, focussing on the specific case of the *RideMyRoute* App. The paper draws on findings from the EU-funded SocialCar project, which has designed, developed and tested *RideMyRoute*, a journey planning App that allows users to discover and make connected journeys involving carpooling and public transport.

Section 2 provides a brief overview of the state-of-the-art in intermodal journey planning with a focus on carpool to public transport journey planning solutions. Section 3 describes the intermodal algorithm developed in the SocialCar project and highlights the data sources and data exchange procedures used to feed the algorithm. Section 4 introduces the practical application of the SocialCar algorithm through development and deployment of the *RideMyRoute* journey planning App. Section 5 presents an evaluation of results and experiences from use of the *RideMyRoute* App by actual travellers in their real travel environments at four sites (Brussels, Edinburgh, Canton Ticino and Ljubljana). Section 6 provides a discussion of research findings and conclusions.

2. Intermodal carpool journey planning: state-of-the-art

End-to-end carpooling (i.e. carpooling for the entire journey) matches are constrained in 3 dimensions: origin, destination and time of travel, which requires a high density of trip offerings in order to consistently find suitable matches. While trip offers can be accepted if their origin and/or destination is along the route of the trip offer, introducing some flexibility to the origin and destination (i.e. points within a maximum deviation of the driver's route), this remains a tightly constrained problem requiring a high trip-offer to trip-request ratio. This is often not achievable in medium and low-density areas. Where carpooling is considered as a feeder to public transport in an intermodal journey the matching problem is relaxed as multiple destinations become possible at numerous stops on the public transport network. This makes the possibility of matching carpool offers with requests much more likely, especially where the density of trip offers is likely to be lower, such as in suburban areas.

While there are many new urban travel information apps emerging (some of which purport to be MaaS systems) that provide multi-modal journey planning solutions for the end-to-end journey, few of these provide inter-modal solutions which incorporate more than public transport and walk modes. Very few travel information apps exist which provide solutions that combine public transport with carpooling. Some established intercity/long distance journey planning tools (e.g. *Rome2Rio*, *FromAtoB*), however, are now integrating carpool options from partner carpool service providers (*BlaBlaCar*). This integration allows users to see carpool offers alongside other means of transport for the whole journey, but also suggests connections that combine carpooling with other transportation means. However, no time of travel information is requested as an input to the journey query in these tools and so results cannot be tailored to the user's time of travel. Only day of travel and origin/destination locations are considered in the intermodal journey algorithm. The intermodal possibilities returned to the user therefore require substantial extra investigation by the user to check availability/suitability at the time the user wishes to travel.

Recent enhancements to some mainstream journey planning apps (e.g. *Citymapper*, *Google Maps*, *Moovit*, *Moovel* and *AllyApp*) now offer intermodal solutions involving connections to public transport services from taxi or ridesourcing (e.g. *Uber* or *Lyft*). However, none of these consider carpooling connections to public transport. Furthermore, the taxi/ridesourcing connections are limited to extensions to the public transport solution closest to the start and end points of the journey query. In a similar fashion, the *Qixxit* multimodal journey planning app, available across Germany, returns search results for immediate travel which includes possibilities of using dynamic/real-time carpooling (using carpool services provided by *Flinc*) for the whole journey or to connect to public transport services. All of the above intermodal solutions are based on algorithms that apply sequential substitution (see Fahnenschreiber et al., 2016; Varone & Aissat, 2015). That is, they first calculate traditional multimodal journey paths containing, e.g. bus, train, and walking; in a second step, they try to substitute parts of this trip with carpooling/Uber/taxi. They use the stops from the calculated traditional path to find carpooling offers that can feasibly substitute parts of the trip. A travel leg from the traditional route is only substituted by carpooling (or taxi or Uber) if it improves the objective function (e.g. making the trip faster, cheaper, or a combination). In most applications, substitution is only considered for the first and last legs of journeys and not intermediate legs. Consequently, an intermodal path with carpooling can only be calculated if a traditional public transport/walk journey solution exists. Therefore, carpooling is only considered as a substitute and not as a fully-fledged part of the multimodal network.

Modelling work by Stiglic et al. (2017) on the benefits of integrating carpooling with public transport suggests that for optimal integration only about 25% of carpoolers should be dropped off at the public transport stop/station that is closest to their origin. It is often more convenient for a connection to be made to public transport at a stop/station closer to the urban centre, especially where more frequent departures and faster public transport services operate. They also show that full integration of a carpooling system and a public transport system (rather than the sequential substitution approach) can significantly enhance mobility and increase the use of public transport.

The next section describes the intermodal algorithm developed in the SocialCar project, and applied in the *RideMyRoute* App. The algorithm seeks optimal carpool connections to public transport services at any public transport stop, not just for first and/or last leg extensions of public transport solutions returned by unimodal journey planning algorithms.

3. Description of the SocialCar algorithm

The SocialCar algorithm is a shortest path algorithm that can compute the shortest (according to a performance indicator such as time, cost, number of transfers, etc.) route connecting two locations via a number of intermodal links. The path from origin to destination can be performed using a single transport mode, but also any combination of available options, according to the user preference. The algorithm considers not only public transport options such as buses, trains, trams, and subways, but also carpooling offerings.

In order to solve such a problem, different transport options need to be structured as separate layers in a multi-layer temporal network (Gallotti & Barthelemy, 2015). Each layer consists of a network represented as a graph composed of nodes (junctions or stops) which are connected by arcs (road links or public transport links). Nodes that are present in multiple layers simultaneously represent intermodal connection points. There are also interlayer links which represent the travelling time (by foot) required to transfer from one transport mode to another. The nodes where a modal change can take place are defined as switch points. Public transport layers are represented by time dependent graphs as they only exist when a public transport service is scheduled according to its timetable (Holme & Saramäki, 2012). Carpool trip offers (origin point, destination point and departure time) are also represented as separate time dependent graphs. This requires that a route and set of stops (modal exchange or switch points) between carpool origin and destination are generated by the SocialCar algorithm. The route is generated based on the direct driving route with 'stops' inserted at points along the direct driving route between the carpool origin and destination. These carpool stops were designated as switch points when they were in the vicinity of stops on the public transport network. The weighting associated with interlayer transfer links can then be adjusted to control the level of deviation permissible from the carpool direct driving route. The structure of this multilayer approach is illustrated graphically in Figure 1.

Conventionally in multilayer networks these interlayer transfer links are considered as 'walk' links, but for carpool to public transport connections they are driven rather than walked, since the carpool driver can deviate from their direct route for pick-up and drop-off of passengers. This effectively incorporates a degree of flexibility in the carpool route, allowing deviation from the most direct carpool route to facilitate a greater number of intermodal carpool to public transport connection opportunities. In urban areas the number of public transport stops in the vicinity of the carpool route can be very high and so a minimum distance between carpool switch points has been applied. Outside urban areas, where public transport stops may be very far apart, a network of potential 'first' pick-up and 'last' drop-off points have been added. An important consideration here is that the carpool pick-up and drop-off points automatically generated by the SocialCar algorithm are an approximation – in reality their precise location will still need to be approved by the carpool driver and passenger at the booking stage.

The advantage of a multi-layer temporal network structured as described here is that traditional shortest path algorithms work with few modifications. In order to find routes that are better suited to the users' preferences, the single objective function of the original Dijkstra's algorithm was modified by adding more objectives including travel 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. The weightings are derived from preferences provided by the user in their user profile. If the user has not provided preferences relating to these attributes then it is also possible to generate multiple solutions by calling the algorithm several times with adjusted weightings, e.g. to generate a solution with, for example, more changes but less total travel time, or increased carpool time and less public transport use. Further details on the SocialCar algorithm can be found in Jamal et al. (2017).

Some constraints have been placed on the sequence of connections possible in the intermodal routes generated by the algorithm. Walk and carpool modes are possible for the first and last connections of a journey but no constraint is placed on the location of the connection point other than it being a public transport stop switch point. Therefore, it needn't be the closest public transport stop to home. Walk legs are also possible for intermediate connections between public transport legs. Public transport modes are possible for any intermediate legs. Carpool legs are not possible as intermediate legs – they must form either the first or last leg of a journey, or they can form the entire journey. The use of bikes (bike-share) is not included in the current version of the algorithm but could be added in future.

3.1 Data Sources and Exchange

The algorithm is limited only by data availability; performance is not an issue, given that these types of algorithms run in pseudo polynomial time (O(n log n)). The present version of the algorithm runs on deterministic data: the travel times on the network arcs are given and known deterministically in advance. Even if the travel times change in real-time, the algorithm will run without any modification, as it would be called "on demand" by the client software (i.e. the *RideMyRoute* app).

For representation of public transport services the current adopted format is GTFS (General Transit Feed Specification: http://gtfs.org/). A novel approach is adopted for carpool data, whereby the carpooling trip offer data is also modelled as a public transport offering, with each carpooling offer converted to a single instance equivalent public transport route (with capacity limited by the available number of seats) and formatted according to GTFS. To achieve this, a simple procedure has been developed within the SocialCar algorithm to derive a list of sequential public transport stops, with associated times (see discussion above).

The APIs which exist for many carpool service providers (CSPs) allow third party apps and services to query the carpooling data with the transfer of a member's name, origin and destination locations and the start time at origin location in response to an individual query. This is sufficient information to generate public transport equivalent carpool routes in GTFS format, but only on suitable carpool offers specific to the individual request. This approach has the advantage that the CSP is only exposing journey data required to provide individual matches as and when required (in response to a specific query) with all data certain to be up to date. In this case the carpool providers would also hold complete ownership over their data, avoiding any potential legal and privacy issues. However, this approach has severe limitations for generating the most suitable intermodal options because possible carpool connections are not returned for the full range of plausible public transport stops. Instead carpool connections are considered only for extension of the first/last miles of the returned public transport solutions that are closest to the start and end points of the journey query. Furthermore, the data exchange process and subsequent conversion of returned data to GTFS format will all need to be done while the user is waiting for a response to their journey planning query, which results in unacceptably long response times.

An alternative approach, which has been adopted by SocialCar, is the transfer of all CSP carpool offers every 24 hours. These are batch converted to GTFS routes for use by the SocialCar algorithm. As SocialCar is not working with real-time carpooling services the number of new offers within the day of travel are relatively small, but if there is a change to any of the carpool offers at the CSP end (since the last update) then an immediate update of only the changed offer is transferred to SocialCar. The advantage of this approach is that all carpool data is held locally by SocialCar and has been pre-converted to the GTFS route format required by the SocialCar algorithm. As a result, the time to respond to a *RideMyRoute* user query is far lower. This also places much less strain on the CSP servers with the bulk of the data transfer timed to happen overnight when no other demands exist. The primary advantage is that truly inter-modal solutions can be sought by the algorithm for connection at any public transport stop, and not just for first and/or last leg extensions of the public transport solutions closest to the start and end points of the journey query. Stiglic et al. (2017) demonstrate that optimal intermodal solutions are more likely to occur when carpool connections are made, not to the closest public transport stop, but to the public transport stop which allows connection to the fastest and most frequent public transport service (e.g. to a commuter light rail / metro service rather than a local bus).

4. Practical Application (*RideMyRoute* App)

The conceptual design of the SocialCar system is shown in Figure 1. The design was developed within the SocialCar project in 2016/2017 and deployed through the *RideMyRoute* App in both Android and iOS versions. The App was launched and trialled in four participating cities/regions (Brussels, Belgium; Edinburgh, Scotland; Canton Ticino, Switzerland; Ljubljana, Slovenia) between September 2017 and January 2018.

4.1. Background to the trial cities

The characteristics of the test sites are summarised in Table 1. We can see that there are variations between sites in terms of geographic area, population, car and public transport modal split and degree of congestion. Table 1 also indicates variation in current levels of carpool availability. Common to all sites were problems of recurrent traffic congestion in the peak hours, with a high proportion of commuting into the city from the suburbs and hinterland. At all sites there were central parking restrictions and higher central parking costs in place accompanied by free or relatively low cost park and ride on the edges of the city.

Public transport within the city of Brussels is extensive, comprising bus, tram, metro and train, much of which is segregated from the road network (Poelman and Dijkstra, 2015). Despite this, the Brussels Region experiences severe and widespread congestion problems partly caused by federal tax benefits provided to employers and employees using company cars. More than 50% of the daily commuter population travels from the outer regions to the Brussels-Capital Region for work, contributing significantly to the congestion. Train services operating to the main settlements in the wider region and beyond are insufficient for the demand and during rush-hours are congested, limiting choice for commuters. Park and Ride (P+R) facilities are provided mainly at the outer edges of the metro network.

Ticino has traffic congestion problems during peak hours in the principal (small) cities of Lugano, Bellinzona and Mendrisio, on the main routes into and from these cities and on routes from and to the national border with Italy. Train and light rail services connect the main towns while local services are provided by bus. There has been recent investment in new public transport services which are segregated from the road network and new stations to access these public transport services. There are 39 P+R facilities near train stations, and in Lugano two direct city bus lines connect P+R to the city centre.

Edinburgh has significant and increasing congestion in the peak hours. To combat this, the city has parking and access restraint measures in place in the centre (Edinburgh has the second highest city centre parking charges in the UK, behind central London) and is investing in new public transport infrastructure. There is a good quality bus network operating in the city with dedicated bus lanes on main routes, as well as a new tram line and a number of commuter rail services. Investments in new rail stations and new routes as well as the new tram line offer greater opportunity for commuters to P+R.

Ljubljana is a compact city that has developed within the ring road around the city, while settlements are expanding outwards from the city centre along main corridors in five directions. Congestion associated with the daily commute is becoming one of the biggest problems in the Ljubljana region. Public transport comprises of a rail network connecting the main settlements across the country with Ljubljana, and within the city a bus network. Four P+R by bus sites exist at the edge of the city. Carpool activity is centred on connecting commuters from outside the city to the rail network on the edge of or outside the city.

Table 1 Overview characteristics of the test sites

Site	**Area description**	**Area size**	**Region population (city population)**	**Congestion levels**	**Modal Split**		**Average number of carpool lift offers each weekday** (main carpool service provider)
					Car	**PT**	
Brussels	Functional Urban Area with single main city	1614 km²	2.6m (1.16m)	Severe	*45%*	*32%*	200 *(Carpool.be http://www.carpool.be)*
Canton Ticino	A region which includes a number of cities	2,812 km²	350,000	Significant on specific routes	*72%*	*15.4%*	300 *(BePooler http://www.bepooler.ch and MobAlt http://mobalt.ch/)*
Edinburgh	Region with single main city	460 km²	1.55m (500,000)	Significant	*54.3%*	*16.2%*	450 *(Liftshare https://liftshare.com/uk)*
Ljubljana	Region with single main city	272 km²	537,000 (280,000)	Hot spots on main routes into city and ring road	*58%*	*13%*	500 *(Prevoz https://prevoz.org/)*

4.2 Data feeding the *RideMyRoute* App during the trial

The SocialCar intermodal route planning algorithm and ride-matching algorithm were fed with GTFS public transport data and GTFS-formatted carpool trip offers (as described in 3.1 above). Public transport data was accessed from published open data or provided directly by the city authority. Average travel times for traffic based on distance travelled and road type were applied. Constant values were applied throughout the day rather than time dependent values, with the intention being that real-time data would be used to adjust these constant travel time values once available. Network status updates and user tracking were incorporated where available to provide real-time updates to travellers. A simple user reputation function for carpool drivers and passengers was also incorporated. The carpool trip offer data was shared by the Carpool Service Providers in each site using the rideshare data exchange protocol (RDEX) developed by SocialCar partner Taxistop and enhanced during the project. Additionally, it was possible for users (drivers) to offer carpool trips directly through the *RideMyRoute* App, allowing the App to be deployed in locations without existing established carpooling services. The reader is referred to SocialCar Project (2017a) for full technical details on the testing of these algorithms and integration of the data including the RDEX protocol and its use. The daily average number of carpool lift offers transferred using RDEX to SocialCar from each CSP is illustrated in the final column of Table 1.

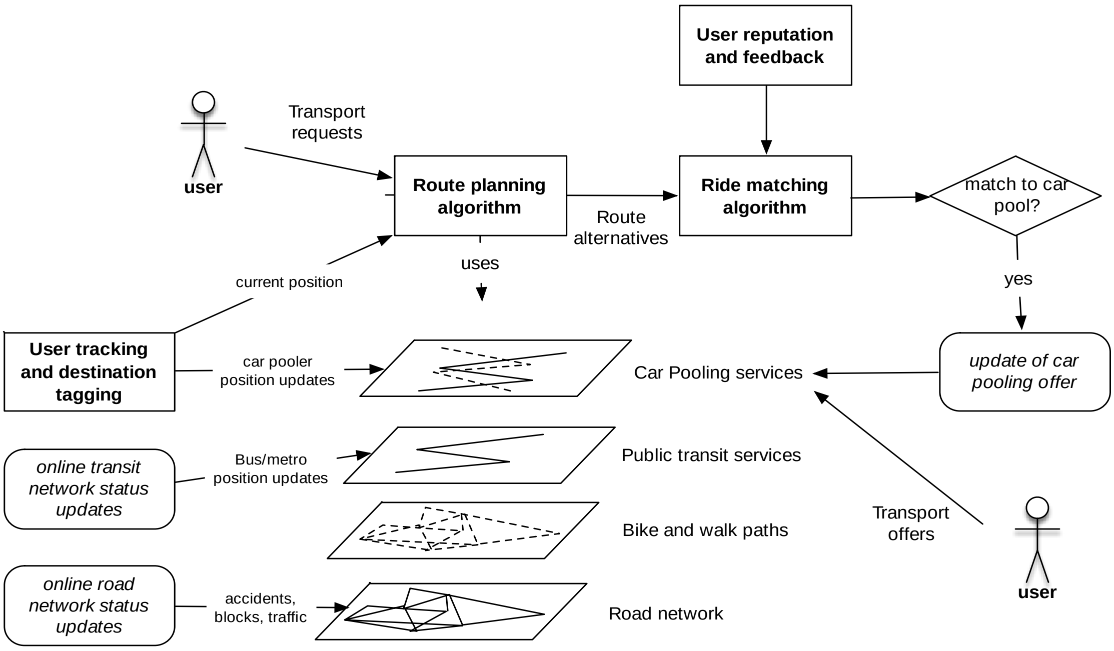

Figure 1 Conceptual design of the SocialCar system (SocialCar Project 2017b)

5. Results from *RideMyRoute* trial

The trial involved the use of the *RideMyRoute* App by actual travellers in their real travel environments at four sites (Brussels, Edinburgh, Canton Ticino and Ljubljana). In total the number of users of the App across the four sites during the trial period was 236, of which 124 signed up as formal testers who completed in-depth 'before' and 'after' surveys, with around half of these formal testers providing further feedback through focus group participation. The recruitment process for formal testers involved a combination of paid Facebook campaigns, press releases and radio coverage to target a wide range of citizens, alongside more direct promotion to large organisations/employers via newsletters and e-mail. A range of incentives were offered to formal testers completing the testing and feedback process, including entry to prize draws for the following prizes: dinner for 2; free public transport travelcards (monthly); folding bicycle; smartphone. Promotion was also scheduled to coincide with European Mobility Week activities to enhance recruitment options. There was an even split between Android and iOS users during the trial. The average age of testers across sites was in the mid-thirties with very few formal testers over 55 years old (2 out of 124 testers). The cohort of formal testers also tended to have slightly lower levels of car ownership and shorter travel distances, with a larger proportion using public transport for their most frequent journeys than the average for their city/region. This should be borne in mind when considering the results and feedback received. The formal testers also tended to have greater comfort with smartphones and experience with existing journey planning tools than the average population in their cities. This is considered an advantage as it makes them more likely to be able to provide feedback informed by experience with similar technologies.

5.1 Automated monitoring: use of the *RideMyRoute* App

Table 2 presents an overview of the use of the Trip Planning function of the *RideMyRoute* App and the extent to which this led to increased carpooling activity. In total the number of Trip Planning solutions provided to users of the *RideMyRoute* App during the trial was around 15,000. The total number of solutions which included a carpooling offer totalled 2781 across all 4 sites. This represents an average of 19% of all solutions presented to users, i.e. 1 in 5 trip planning solutions contained a carpool component in the route offered to users. It should be noted that this varied significantly between sites with an average of only 5% for Brussels compared to 41% in Ljubljana, reflecting the variation in average number of carpool offers available for each site (as detailed in Table 1) relative to the geographic area covered in the trial. Larger areas with fewer carpool offers result in lower rates of carpool options in solutions. In cases where carpooling was not suggested, this was mainly due to no suitable carpool offers being available at the times requested. The total number of Trip Planning solutions which resulted in users actively pursuing carpooling totalled 406, or 15% of the solutions containing a carpool option. This varied by site from 13% at Ticino up to 23% for Brussels.

Table 2 Overview of 'Trip Planning' solutions returned to *RideMyRoute* App users during trial

	Number of Registered Users during Trial period	Number of Trip Planning solutions returned to users	Number of solutions with carpooling options	% of solutions with carpool option	Number of solutions resulting in an enquiry to carpool	% of solutions with a carpool option resulting in enquiry to carpool
Brussels	46	1225	60	5%	14	23%
Canton Ticino	117	9801	2084	21%	267	13%
Edinburgh	36	2946	232	8%	40	17%
Ljubljana	37	980	405	41%	85	21%
TOTAL	**236**	**14952**	**2781**	**19%**	**406**	**15%**

As SocialCar has the primary objective of increasing carpooling possibilities by combining carpooling to public transport services, an interesting output is the proportion of 'trip solutions with carpooling options' which suggest a connection from carpooling to a public transport service compared to simply carpooling for the full length of the journey. From Table 3 we can see that at all sites the vast majority of trip solutions that include carpooling are where carpooling provides a connection to public transport services. At three sites (Brussels, Ticino and Ljubljana), over 86% of solutions with carpooling involve carpool connections to public transport services. Therefore, users at these sites were offered *seven times more* carpool possibilities in comparison to existing carpool only apps. This significantly reduces the spatial density of trip offers required to find potential carpool matches. At the Edinburgh site, this figure is lower at 69%, or over three times more carpool possibilities in comparison to existing carpool-only apps.

Table 3 Overview of carpool options within 'Trip Planning' solutions returned to *RideMyRoute* users during trial

	Number of solutions with carpooling options	% solutions with carpool options which are	% solutions with carpool options which are carpool to PT connections

		carpool only rides	
Brussels	60	3%	97%
Canton Ticino	2084	13%	86%
Edinburgh	232	31%	69%
Ljubljana	405	9%	91%

5.2 User feedback from the *RideMyRoute* trial

A 'before' and 'after' survey delivered to the formal testers was designed to identify the factors which most influence their attitudes towards using the *RideMyRoute* App and to gauge the extent to which use of the App would ultimately change their travel behaviour. The survey was based on the Technology Acceptance Model (TAM) framework as developed by Davis et al. (1989) and cited in most of the research that deals with user acceptance of technology (Chuttur, 2009). TAM describes a well-established and accepted methodology to understand the relative extent to which different factors influence intention to use new technologies. This allowed a comparison of perceived ease of use, perceived usability, perceived trust, intention to use the App and likelihood of use of the App changing travel behaviour, both before the trial (based on watching the *RideMyRoute* video illustrating the features and use of the App) and after the trial (based on tester's actual experience using the *RideMyRoute* App). The after survey also incorporated questions to allow derivation of the score on the System Usability Scale (SUS) (Brooke, 1996; Brooke, 2013), as well as comparison of various features of the *RideMyRoute* App with other journey planning services/apps which they had used. Finally, there were questions relating to overall satisfaction with the *RideMyRoute* App and whether testers would recommend its use to friends. The reader is referred to SocialCar Project (2018) for fuller description of the method, surveys, and results analysis summarised in this section.

The scores for ease of use of the App were higher than those for usefulness at all sites, with Edinburgh testers slightly disagreeing that the App was easy to use, Ticino testers being neutral and Brussels and Ljubljana testers slightly agreeing that the App was easy to use. The testers at all sites were neutral about whether they could trust the information received from the App; however, testers at all sites were in agreement that they could trust *RideMyRoute* to look after their personal data. A further means of assessing usability is through the System Usability Scale or SUS (Brooke, 1996). The SUS is based on answers to 10 questions which were included in the post-trial surveys. This scoring system provides a means of comparing responses between different apps and allows benchmarking with other new technology implementations. For instance, the average SUS score from over 500 studies is a 68 (out of 100) and so an SUS score above a 68 would be considered above average and anything below 68 is below average (Brooke, 2013). Based on data on the use of SUS from more than 3,500 SUS studies, Bangor et al (2008, 2009) have established the relationship between SUS scores and people's ratings of systems and products they were evaluating in terms of adjectives such as "good," "poor," or "excellent". The graded rankings they propose is displayed in Figure 2. Table 4 presents the SUS scores achieved at the 4 SocialCar sites. All sites produced an SUS score below the SUS average score of 68. The relatively low SUS score and poor 'usefulness' rating for Edinburgh is perhaps explained by the issues encountered at the Edinburgh site as discussed in Section 5.4.

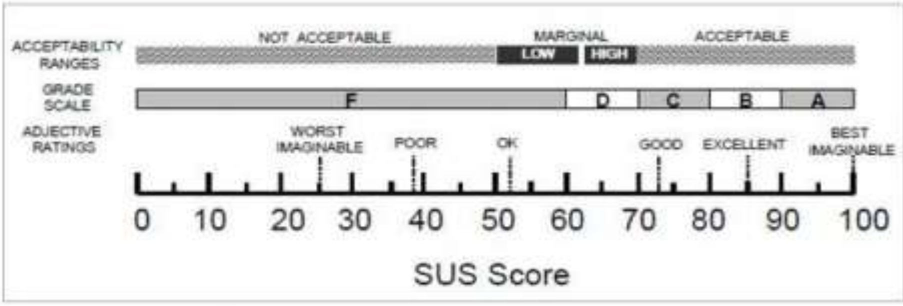

Figure 2 Grade rankings of System Usability Scale scores (source: Bangor et al. 2008)

Table 4 SUS scores for the *RideMyRoute* App

	SUS score	Adjective Rating	Acceptablility Rating
Brussels	67	GOOD leaning towards OK	High Marginal Acceptability
Canton Ticino	59.6	OK leaning towards GOOD	Low Marginal Acceptability
Edinburgh	49.1	OK leaning towards POOR	Not Acceptable
Ljubljana	64.3	GOOD leaning towards OK	High Marginal Acceptability

Considering testers' overall satisfaction with the *RideMyRoute* App, satisfaction levels were highest at the Ljubljana site, with almost 50% of testers being "satisfied" or "very satisfied" and only 25% being "dissatisfied"/"very dissatisfied". This is possibly due to there being fewer good quality existing journey planning tools at this site. Brussels had the second highest satisfaction rating (41%) while the worst was Edinburgh with only 30% satisfied/very satisfied and 40% dissatisfied/very dissatisfied. When asked if testers would recommend the *RideMyRoute* App to a friend or relative, again Ljubljana and Brussels ranked highest with 55% of testers stating they would, 47% of testers from Ticino stating they would, while Edinburgh ranked worst with less than 40% stating they would recommend the App to a friend or relative.

Testers who had experience of using other existing journey planning apps / services were asked how the *RideMyRoute* App compared. This revealed that at least half the respondents, at all sites except Edinburgh, considered *RideMyRoute* about the same or better for overall experience than the existing journey planner they have experience using.

Figure 3 illustrates that satisfaction ratings are much higher amongst those who stated intention to use carpooling as a result of the *RideMyRoute* App compared to those who didn't. The aggregate across all test sites shows 41% of testers with intention to carpool were "satisfied" or "very satisfied" with the *RideMyRoute* App with 29% "dissatisfied" or "very dissatisfied". This compares to only 9% of those with no intention to carpool expressing they were "satisfied" or "very satisfied" with the *RideMyRoute* App and 65% "dissatisfied" or "very dissatisfied". Figure 4 shows that of those stating intention to use carpooling as a result of the *RideMyRoute* App, 55% would recommend the App to a friend, but only 17% of those with no intention to carpool would recommend its use to a friend. This highlights the added value of including carpooling options in the solutions presented through travel information tools.

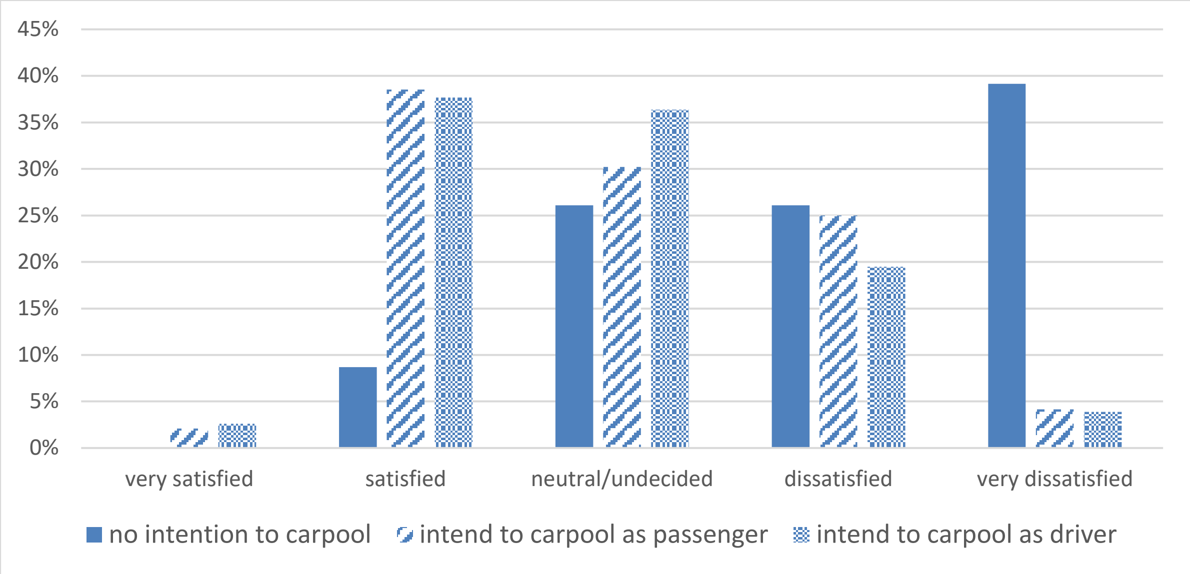

Figure 3 Overall satisfaction with the *RideMyRoute* App amongst those with intention to carpool

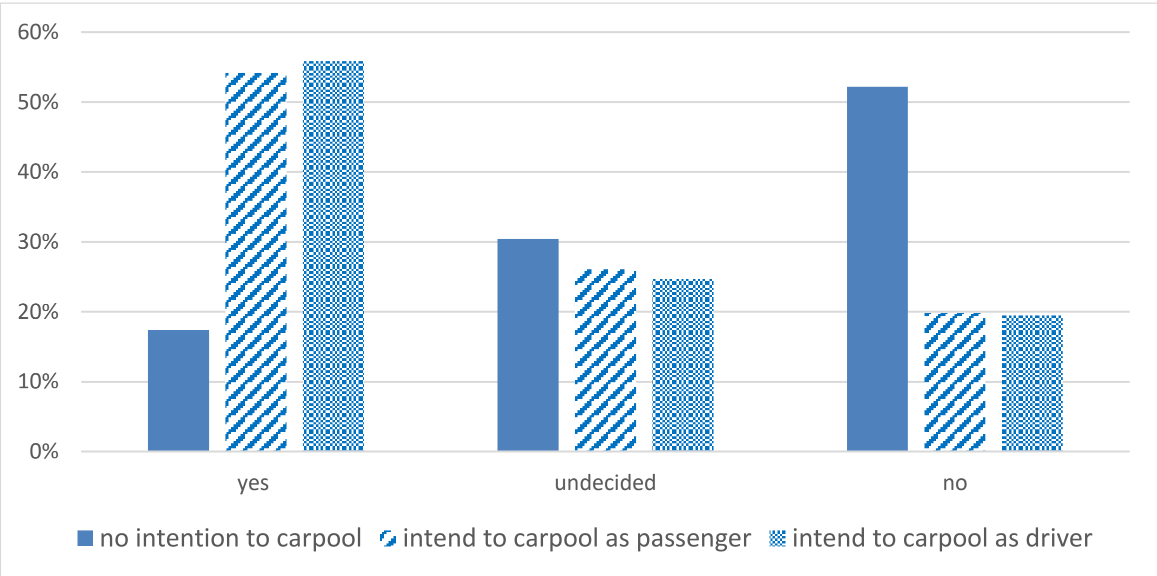

Figure 4 Responses to "Would you recommend the *RideMyRoute* App to a friend/relative/etc." amongst those with intention to carpool?

5.3 Intention to Use the *RideMyRoute* App

Considering stated intentions towards using the *RideMyRoute* App in the future, we see from Table 5 that on average around a third of testers stated they intended to continue using the App in the future. Over a fifth of these expressed they would be likely to drive less and between 40% and 50% would be likely to carpool more as a result of using the App.

Table 5 Stated intention of formal testers to use the *RideMyRoute* App in the future and its likelihood to change travel behaviour

	Stated Intention to use the *RideMyRoute* App in future	Likelihood to Drive Less	Likelihood to Carpool More	Likelihood to use PT More
Brussels	33%	7%	15%	11%
Canton Ticino	38%	12%	19%	15%
Edinburgh	23%	5%	9%	7%
Ljubljana	34%	12%	13%	6%

A much larger pre-trial survey (with sample size of 1072 respondents) was conducted to examine the stated intentions towards using the *RideMyRoute* App in the future from a representative mix of citizens reflecting the demographics and current travel habits in the four test cities. These respondents were asked to view a video explaining what the App could do and how it would work[2], prior to completing the surveys, but they did not actually use the App. Detailed description of the design and analysis of results from these surveys are presented in Wright et al. (2018). The main findings from this larger sample revealed the following characteristics of those stating Intention to Use the *RideMyRoute* App.

- There is little difference between male and female respondents.
- Intention to Use *RideMyRoute* decreases with increasing age and increasing income; this might be related with both higher comfort with smartphone technology and with lower individual car ownership by younger people. Comfort with using smartphone app technology is the most significant user characteristic affecting Intention to Use *RideMyRoute*.
- Households with access to a car have a 33% stated Intention to Use *RideMyRoute*; this suggests that it is not only attractive to households without car access.
- Those respondents who currently travel by bus for their most frequent journey show the highest Intention to Use *RideMyRoute* (45%); high Intention to Use by bus users might be related to the low average speed of buses and expected reduction in travelling times if they can use carpooling to connect to faster (possibly rail based) and more frequent public transport services.
- Intention to Use increases with increasing travel time; when journeys are short, there is less need to look for alternatives and multi-mode trips incur connection times which are relatively high, as a proportion of the overall journey time. Instead, when travelling times are longer, connection times are a relatively smaller component of overall journey time, and multi-mode alternatives may result in shorter overall travel time if *RideMyRoute* can direct drivers to connect onto fast public transport services for a significant part of the journey. This suggests suitability for suburban to urban trips rather than trips entirely within urban areas.
- Experience of regular congestion and delays outweighs experience of using carpooling or of using other journey planners or social media, in Intention to Use *RideMyRoute.*

5.4 Focus group feedback and issues identified

The user feedback from formal testers attending focus groups revealed that many issues remained relating to the quality and accuracy of the trip planning information returned to some users. This was especially prominent at the Edinburgh site. Investigations with the developers of the software and

[2] The English version of this video is available here: https://www.youtube.com/watch?v=AYTHAWSlWFA

data interfaces, as well as with the implementers at each site, revealed that the causes of these issues were largely related to the accuracy or completeness of the data from external sources feeding the App, resulting in unsuitable or unacceptable results. Specific problems identified related to:

1. Limited availability of certain types of data (e.g. real-time data, fare data), and limited coverage of data (e.g. real-time data, parking data) led to certain planned functions remaining undeveloped or unavailable for use.
2. Poor quality of data (e.g. GTFS bus data missing intermediate stop timings), combined in some cases with limited coverage (e.g. gaps in mapping address data especially in rural areas), led to accuracy and completeness of results being impinged.
3. External organisations (e.g. carpool service providers) with proprietary software do not create and store data in consistent ways. This makes use of standard protocols for exchanging data more difficult, requiring extra effort to process data at the delivery end. If the organisation delivering the data has little incentive to conduct this data processing thoroughly, then the result is that poor quality data is exchanged. SocialCar experienced this issue with carpool trip offer data where return journeys and repeat journeys were not always received.

The other main issues identified during the focus groups as limiting the effectiveness of several of the App functions related to the lack of a critical mass of users (carpool trip offers and App users providing ratings and exchanging incident information with each other) and the lack of real-time status information for both carpool and public transport legs of the journey. All of these were mentioned as attributes which would add value to the product. Their lack of use/omission undoubtedly reduced the attractiveness of the App during the trial.

Interestingly, none of the testers attending the focus groups expressed any concerns relating to data privacy and all were happy to share their data if they perceived a benefit from this. This is consistent with the user survey feedback on trust where testers at all sites agreed that they could trust *RideMyRoute* to look after their personal data.

6 Discussion and Conclusions

The research questions which this paper seeks to address are: how can information on carpooling be incorporated within a MaaS-type system; to what extent will this increase carpool matches/ possibilities; and is there an appetite from suburban commuters for this type of offering.

Several studies (Tsao and Lin, 1999; Vanoutrive et al, 2012) identify that longer distance trips are more conducive to carpooling, as shorter trips are seen as too onerous once waiting time is accounted for. This is consistent with the results from surveys on Intention to Use the *RideMyRoute* App (Wright et al, 2108). Neoh et al (2018) identify that the ideal characteristics of commuters who will consider carpooling are that they have flexible working hours, access to direct routes or near-direct and swift routes on public transport; and, related to the latter, live in a *Non-urban* area. Figure 5 presents the main carpooling facilitators for commuters according to Neoh et al. (2018). This suggests that combining carpool trips with direct and swift public transport services in suburban and peripheral areas fits several key characteristics of the ideal carpooler profile, which show the greatest potential for travel behaviour change.

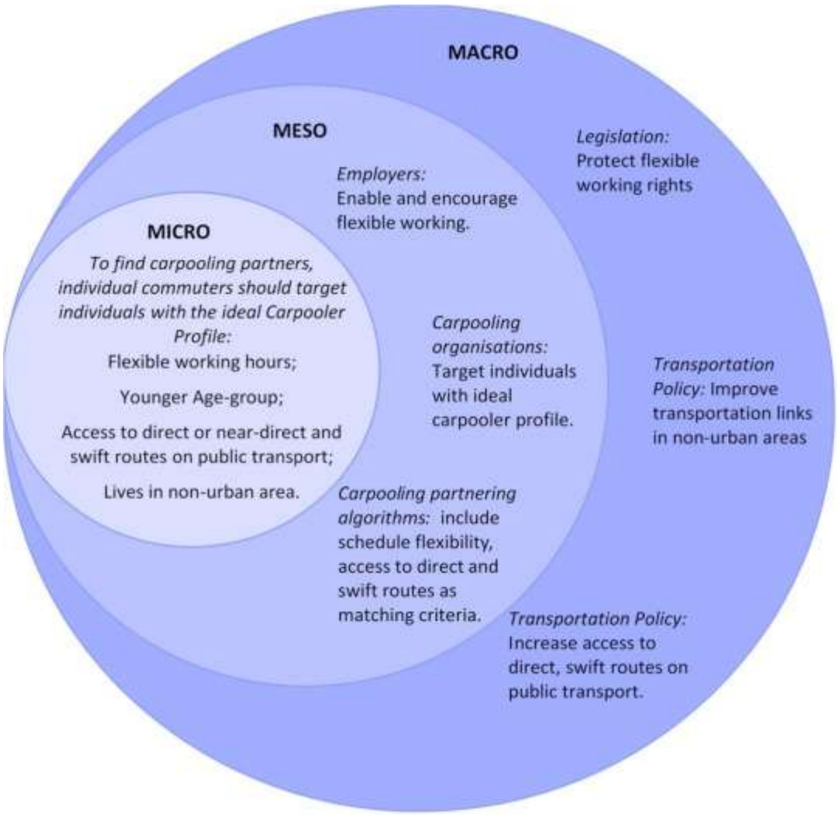

Figure 5. Nested layers of carpooling facilitators for commuters (Neoh et al, 2018)

However, there is a dichotomy between the characteristics of the ideal carpooler profile (longer commuter journeys from non-urban areas) and the likelihood that a passenger request matches a driver offer from these lower density residential areas. Modelling work by Tsao and Lin (1999) investigating the impacts of spatial density and temporal factors on carpool demand concluded that carpooling has little potential for longer suburban commuter journeys due to the difficulties in finding a carpool partner because of the small number of trips from the same origin zone to the same far-away destination zone. This is reaffirmed by later work by Buliung et al. (2010).

The *RideMyRoute* approach, presented in this paper, overcomes this dichotomy by combining carpool trip offers with direct and swift public transport services from suburban and peripheral areas in an intermodal journey planning solution. Results from testing the technical validity of this approach revealed that intermodal carpool to public transport solutions were being successfully generated and that this resulted in almost seven times more travel solutions involving carpooling than carpool only systems. So, while spatial density remains a factor in finding suitable matches, it is much less so with *RideMyRoute* than with conventional carpool matching services. This means that carpool initiatives can be targeted more towards commuters who fit the ideal carpooler profile (Neoh et al, 2018) *and* whose potential for behavioural modification is greatest – i.e. commuters in non-urban areas with a flexible schedule, who have access to direct routes or near-direct and swift routes on public transport. This is a potentially significant policy finding.

In investigating what motivates people to carpool, Bachmann et al (2018) emphasise that carpool systems should be as simple as possible to use, highlighting the need to eliminate obstacles such as not being able to find a carpooling partner. As discussed above, *RideMyRoute* reduces this obstacle especially for suburban commuter trips. Other important factors identified by Bachmann et al are creating conditions of trust, making carpoolers visible and emphasising environmental benefits. Considering the environmental benefits, could the incorporation of carpooling into MaaS lead to reduced car ownership? If the relative travel times and/or costs of driving end-to-end exceed those of carpooling to a public transport connection and using public transport for the remainder of the journey, then this is likely to reduce the use of cars for commuting journeys and may lead to the removal of the need for second (or third) cars in suburban areas. As discussed above this is most likely to happen for longer commuter trips from suburban areas where congestion and parking are significant problems near the destination end of the trip. Pre-trial surveys (n=1072) revealed that those respondents from households with two or more cars (40% of households) have, on average, a 21% intention to use *RideMyRoute* (Wright et al, 2018). From those respondents with intention to use *RideMyRoute* who currently drive for their most frequent journey, 20% stated a willingness to carpool as a passenger for most journeys to work and a further 40% stated a willingness to carpool as a passenger for some journeys to work. There is potential for those showing willingness to carpool to work as a passenger for most commuting journeys to give up their second car. This amounts to a potential reduction in car ownership, in this sample, of approximately 4% of all second cars, or a 1.7% overall reduction in car ownership. There is also some potential for those showing willingness to carpool to work as a passenger for some commuting journeys to give up their second car, although further study would be required to establish the extent of this.

In Table 2, the % of solutions with carpool options (matching rates) hints that an increase in solutions is linked to density of trip offers, but other factors also influence this such as the density of the public transport network. Brussels displays the lowest number of trip offers (average of 200 per day -see Table 1) across a large area of 1614km^2 resulting in a trip offer density of 0.124 trips /km^2. The matching rate of 5% is lowest at this site. Canton Ticino has 300 trip offers per day across a very large area of 2812km^2 suggesting a trip offer density of only 0.107 trips /km^2. However, the trip offers are concentrated around the main corridors into and surrounding the larger cities in the area and so the trip offer density on these corridors is much higher. There are also good public transport links along these corridors. The matching rate for Canton Ticino is 21%. Edinburgh has the second highest number of trip offers per day of 450 across an area of 460km^2 resulting in trip offer density of 0.98 trips /km^2. However, a relatively low matching rate of only 8% is achieved. This is explained by the lack of public transport options, largely due to the issues with the import of public transport data experienced at this site as discussed earlier. Finally, the Ljubljana site has the highest number of average daily trip offers of 500 while also having the smallest area 272km^2, resulting in trip offer density of 1.84 trips /km^2. A matching rate of 41% is achieved. Although it is difficult to draw unambiguous conclusions from this, it does suggest that the public transport network needs to be adequate and fully represented in the system and carpool trip offer densities of over 1 trip/km^2 are desirable to deliver a good chance of finding a matched solution.

The main limitations of the study, which have impacted on the suitability and usefulness of the solutions returned, related to quality and availability of external data sources. Data quality is a real issue that seems to be particularly concerning when using open source data where quality checks are often lacking and limited coverage/missing data leads to accuracy and completeness of results being impinged. This is illustrated in the results with the Edinburgh site, which had the greatest data quality issues, achieving a three-fold increase in solutions which involve carpooling compared to carpool only systems, whereas the other sites achieved a seven-fold increase. This leads to the following recommendations for future policy/practice relating to data supply for MaaS-type systems:

- Open source data should be subject to more stringent quality control checks before publication.
- Consistency and compatibility of data cannot be assumed even when established protocols are stated to have been followed. Extensive data import (and improving) tools which would provide data quality checks and enable faster/more agile data loading are required.

- Protocols for data exchange of carpool data (and other modes utilising proprietary software) need to have sufficient flexibility to allow data providers with subtle variations in their data structures to easily and accurately apply them.

Another limitation of the approach for exchanging carpool offer data is that real-time carpooling services are not handled easily by the SocialCar algorithm due to the processing time required to convert each carpool offer to GTFS equivalent routes. However, as the majority of commuter carpool offers are recurring journeys at the same time each day, real-time carpooling is less necessary for the commuter journey at the journey planning stages. Of course, changes to planned journeys close to time of travel or due to delays en-route are relevant to commuter trips and the inclusion of real-time tracking of all agents within the planned journey and updates through alerts would greatly enhance the value of the product.

A limitation of the evaluation was that the sample size of full testers was limited. These full testers exhibited slightly lower levels of car ownership and shorter travel distances with a larger proportion using public transport for their most frequent journeys than the average for their city/region. This may introduce some bias to the results presented in Section 5.2, although while lower car ownership might bias towards more intention to use and satisfaction with the *RideMyRoute* App, the shorter travel distances are likely to introduce some bias in the other direction. Furthermore, results from the full testing with a small sample on stated intention to use the *RideMyRoute* App are supported by the pre-trial survey with a much larger sample, the main findings from this being presented in Section 5.3.

In conclusion, the route planning algorithm developed for the *RideMyRoute* App, described in this paper, which combines carpool trip offers with public transport services, offers possibilities for accessing high quality public transport corridors for suburban dwellers. These are the types of trips which fit the ideal carpooler profile (Neoh et al (2018)) and which offer the greatest potential for energy saving potential.

The *RideMyRoute* App has been demonstrated to work in real world environments at four test sites (Canton Ticino, Brussels, Zagreb and Ljubljana). The trial revealed that the App was able to suggest trip planning solutions which included carpool options for one in five journey planning solutions and that the majority (85%) of these were solutions that involved connection from carpool to public transport. This is a significant advance on what is currently available through existing carpool provider systems or journey planning apps/services and reduces one of the major limitations of carpooling - finding carpool matches in residential areas with lower spatial density.

In general, feedback from test users revealed the majority thought the idea was very good and they would find the App very useful in future if the performance issues (related to data quality) could be fixed and real-time data features could be added. If there were future releases of the App that were further developed and the technical/data issues were resolved, they would consider using it again and would also recommend the App to their friends and relatives.

Although the *RideMyRoute* App was trialled as a stand-alone intermodal (carpool to public transport) trip planning tool, its new RDEX protocol for sharing carpool data combined with its intermodal trip planning algorithm provide a fundamental stepping stone towards incorporating carpool services within MaaS-type offerings in the future. From the evidence provided in this paper it is envisaged that this will provide a key component in the transition towards MaaS for suburban areas.

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