

Autonomous vehicle ride-sharing services:

Will they make cities greener,
more efficient and more accessible?

The MERGE Greenwich consortium built a sophisticated transport simulation to evaluate how autonomous vehicles could provide ride-sharing services in the city. This project was the first of its kind to assess whether such a service could be successful commercially, and could help achieve the wider aims of the city for equitable transport. This report shares lessons learned and puts forward recommendations for government and industry.

Consortium members



www.mergegreenwich.com



The report you are about to read marks the culmination of 12 months' rigorous research, testing, simulations, evaluation, analysis and much more. As CEO of one of the organisations that drove forward this work, I am

proud to present the final findings from the MERGE Greenwich Consortium.

As a group, we have sought to provide a blueprint for the delivery of autonomous vehicle ride-sharing services that offer city-wide benefits. This paper provides what we believe to be important insights into the next steps required by government, operators, tech providers and vehicle manufacturers to drive us forward to a shared successful future.

In order to best understand these challenges and potential solutions, the Consortium strove to take the broadest view possible – exploring potential demand for services, citizens' willingness to share a journey, the likelihood of improving outcomes from transport investment and implications for road space.

The potential benefits for citizens of new technology and services are huge – as has been widely noted – such that autonomous vehicles and ride-sharing could help to solve many of the most pressing issues faced by cities including congestion, emissions and accessible transport for all. Where this research really stands out from other projects is through its critical inclusion of how such services could be commercially launched and the necessary customer service offering required to ensure delivery of a service that can be trusted by consumers.

While the Consortium's research has certainly identified benefits, such as reduced travel time, greater convenience and reducing demand for car parking allowing alternative use of space, they also found that the service could have some unintended consequences in the near term if introduced at scale. Modal shift from buses rather than private cars, raising of emissions and potentially greater congestion could occur if the introduction of the service was not synergic with existing transport systems. We are clear that challenges lie ahead and there is a long way to go before the full potential of the benefits are realised.

Urban transport is going to change dramatically over the next five to seven years with uptake of autonomous vehicles and of ride-sharing. These are concepts that will deliver enormous benefits to the public and will help our cities become safer, more efficient and greener – but only if our cities plan effectively for their incorporation into transport networks.

The most difficult challenges remain ahead of us. If we are going to successfully adopt and embrace this technology, and realise the benefits for the good of cities and citizens, we must work in partnership. We look forward to continuing conversations to reach the right framework, one that will allow the synergies between modes of transport to support cities' objectives.

We urge the Government to convene a task force of senior local and national government representatives, and key industry representatives to prepare for this new generation of mobility services. There's a real opportunity for the UK to be a global leader in this area if we grasp the opportunity now.

Sincerely,
Andy Boland,
CEO, Addison Lee Group

MERGE Greenwich team members

Paul McCabe, Director, Corporate Development, Addison Lee Group
Catherine Hutt, MERGE Greenwich Project Manager, Addison Lee Group
Attanaljide Petralia, Project Support, Addison Lee Group
David Skipp, Director, Partnerships & Innovation, Ford Smart Mobility, Ford
Dr. Stelios Karagiorgis, Senior Research Engineer, Ford
Dennis Witt, Supervisor Research and Advanced Engineering Applications, Ford
Dr. Marcus Jones, Principal Consultant, TRL
Yorgos Voukas, Principal Consultant, TRL
Chris Lodge, Consultant, TRL
Haris Ballis, Transport Modeller, Transport Systems Catapult
Rhiannon Hedingham, Team Leader, Transport Systems Catapult
Irina Gerashchenko, Project Manager, Transport Systems Catapult
Dr. Robin North, CEO, Immense
Dr. David Kelsall, Operations Manager, Immense
Vittoria Parisi, Applications Technologist, Immense
Dr. Pau Segui-Gasco, Solutions Engineer, Immense
Trevor Dorling, Managing Director, DG Cities
Heather Yedigaroff, Head of Strategy and Operations, DG Cities
Dr. Kim Smith, Head of Smart Mobility, DG Cities
Balázs Csuvar, Senior Project Officer – CAV Lead, DG Cities
Elizabeth Jackson, Project Officer, DG Cities
Helen Steiger, Project Officer, DG Cities

Acknowledgments

The MERGE Greenwich consortium would like to thank Innovate UK for part-funding this project, which has resulted in knowledge and assets to help the UK remain at the forefront of autonomous vehicle development and deployment. The consortium would welcome interest from other organisations who may wish to develop these assets further. A full list of project assets can be found at the end of this report.

Contents

1. Executive summary	4
Why autonomous vehicle ride-sharing, and when?.....	4
Key findings.....	7
Call to action.....	9
2. Introduction	11
2.1 What is MaaS and why is it relevant for the MERGE Greenwich project?.....	12
2.2 What exactly is autonomous vehicle ride-sharing?.....	12
2.3 Why are electric vehicles important in this context?.....	12
2.4 Why did MERGE Greenwich target 2025?.....	12
2.5 Will autonomous vehicle technology be safe?.....	12
2.6 Why is it important to develop a blueprint for AV ride-sharing now?.....	13
3. Methodology and deliverables	14
3.1 Consortium approach.....	15
3.2 What MERGE Greenwich set out to achieve.....	16
3.3 Deliverables and assets developed by MERGE Greenwich.....	16
4. Blueprint	21
4.1 Demand for AV ride-sharing.....	21
4.2 Service design to meet demand.....	26
4.3 Demand fulfilment.....	28
4.4 Regulation and policy required.....	33
5. AV ride-sharing service blueprints	35
5.1 Baseline assumptions for all blueprints.....	35
5.2 The accessibility blueprint.....	36
5.3 The convenience blueprint.....	38
5.4 The combined blueprint.....	40
6. Results and impacts of blueprint design	42
6.1 Modal shift caused by the introduction of AV ride-sharing.....	44
6.2 Mobility gaps and other benefits to users.....	47
6.3 Impact on traffic and parking.....	51
6.4 Environmental and safety impact of AV ride-sharing.....	55
6.5 Commercial viability of AV ride-sharing.....	58
7. Conclusions and recommendations	67
7.1 What is the blueprint?.....	67
7.2 Recommendations for optimising the blueprint.....	69
8. Final remarks and key recommendation	72
Appendices	74
Appendix 1: Further recommendations for optimising AV ride-sharing services.....	74
Appendix 2: Suggested further research.....	80
Appendix 3: Reports and assets developed by MERGE Greenwich.....	82

1. Executive summary

Envisage a future where all citizens in urban or suburban areas - including the economically disadvantaged, the disabled, the elderly, minors and those with poor mobility choices today - have access to a service which offers affordable, convenient, efficient and clean transport options. Autonomous vehicles, electric vehicles and ride-sharing services which integrate with public transport are all potential components of this future transport vision. Together, presented as Mobility as a Service, these components are expected to transform how all citizens move around our metropolitan areas and improve the quality and health of the environment in which those citizens live and work. But is this realistic?

The MERGE Greenwich project brought together a consortium of industry and public sector transport experts to build a sophisticated simulation of autonomous and electric vehicles providing ride-sharing services alongside current traffic patterns in a geo-fenced area. Set in London's Royal Borough of Greenwich, this was the first project of its kind to assess in detail whether such a service could be successful commercially and help achieve the wider aims of the city for equitable transport.

Over twelve months the team developed innovative transport demand modelling and simulation tools, combined this with deep industry insight, and designed blueprints for autonomous vehicle ride-sharing services. This report details the results of these blueprints and signposts the way forward for introducing autonomous vehicle ride-sharing services appropriately.

Why autonomous vehicle ride-sharing, and when?

Cities around the globe face increasing transport challenges linked to growing populations and are actively looking to autonomous vehicles and ride-sharing services for potential solutions to meet these challenges as part of their transport agendas.

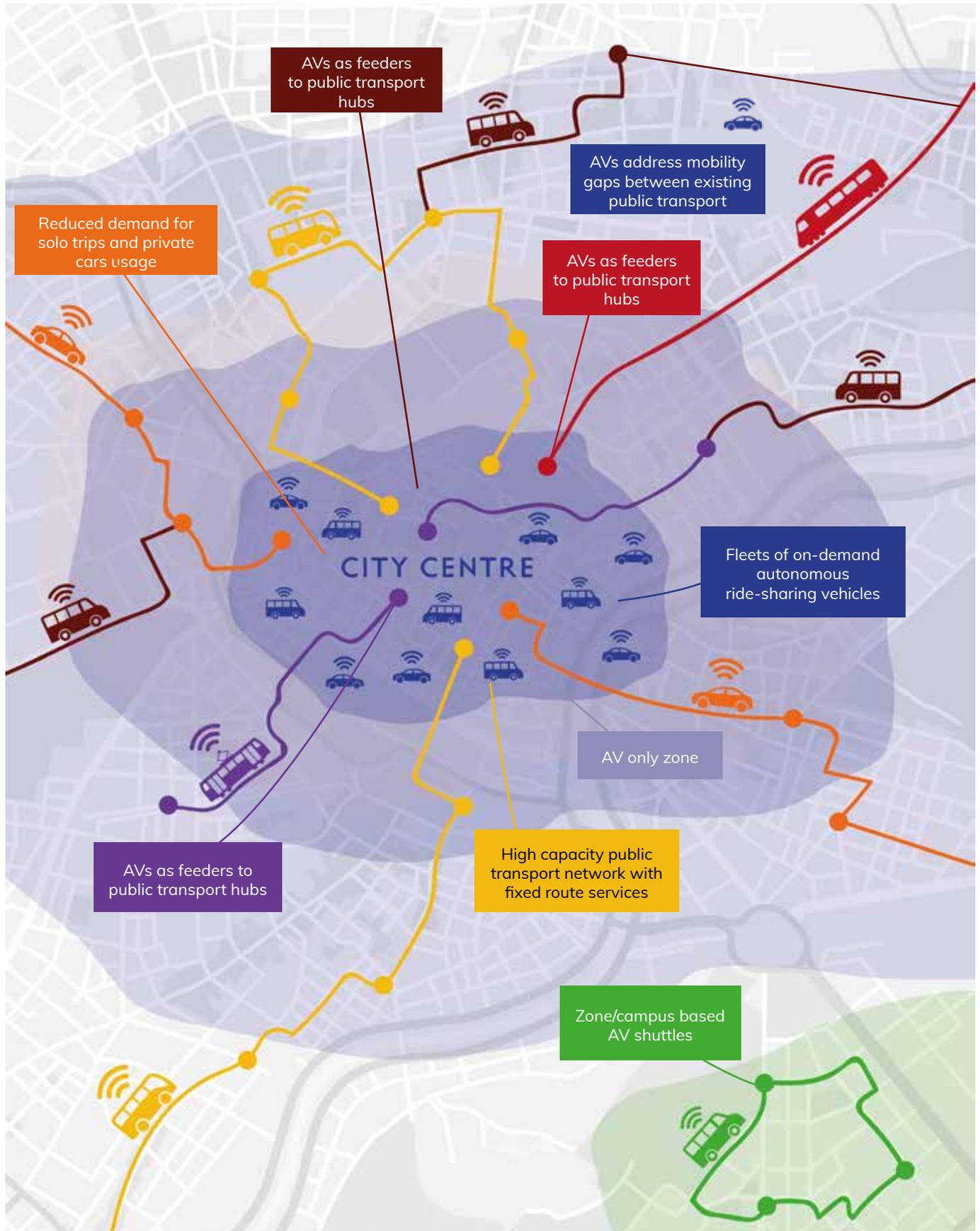
The Mobility as a Service vision for urban environments sees people shifting away from using personally owned cars in favour of using multiple modes of transport. These involve shared trips, which are consumed as a service through a single, unified digital booking and payment interface acting like a 'personal travel assistant'.

Aggregation of services is nothing new in itself: there are plenty of businesses operating today based on aggregating and presenting other parties' services. However, with the advent of autonomous or 'self-driving' vehicle technology and the emergence of ride-sharing business models, whereby people share car journeys with strangers, new possibilities emerge for an additional transport mode to complement existing mass-transit services.

This service could become an integral part of the Mobility as a Service vision by offering solo and shared trips which 'feed' existing high capacity public transport systems including fixed-route buses, tubes and trains, whilst still encouraging people to walk or cycle where it is practical.



Figure 1: The vision for autonomous vehicle ride-sharing as part of Mobility as a Service



The key factors determining the long-term success of these new autonomous vehicle ride-sharing services will be the ability to deliver a seamless customer experience at an acceptable cost to the general consumer without adversely impacting the way the city moves.

If realised, the benefits of low-cost autonomous vehicle ride-sharing services could significantly improve access to transport services throughout the UK and address the two serious socio-economic challenges identified in the government's Industrial Strategy¹ – people's earning power is limited by a lack of mobility and there has been a growing geographical divergence in productivity and opportunities.

While autonomous vehicle ride-sharing in isolation will not resolve these issues, providing frequent, well-routed, affordable and sustainable methods of travel could open up the opportunity for more citizens to become mobile, and for poorly connected areas to be linked to centres for growth and employment.

On the other hand, if autonomous vehicle ride-sharing is not introduced as part of a transition towards Mobility as a Service, it could have adverse consequences by taking too many users from sustainable modes, generating more traffic or encouraging further dispersion of settlement patterns.

In recent years the pace of progress towards mass roll out of autonomous vehicles has picked up. There have been, and continue to be, significant public trials of autonomous vehicles in North America and Asia-Pacific regions. In 2018 the first Society of Automotive Engineers (SAE) Level 4² autonomous ride hailing services are planned for deployment, albeit in US cities which are less complex environments compared to very large urban areas³. Added to this, a number of large car manufacturers and technology companies are working towards SAE Level 4 autonomous vehicles to be commercially available as early as 2021.

With this in mind, the MERGE Greenwich project chose 2025 as the year in which a large scale autonomous vehicle ride-sharing service could, theoretically, be available as part of the wider transport system⁴ in a major cities such as London. In reality, there will be a potentially lengthy transition phase which will require significant progress to be made in areas such as regulation, policy and urban planning to ensure the mass roll-out of autonomous vehicle technology and ride-sharing services can be achieved⁵.



1. <https://www.gov.uk/government/topical-events/the-uks-industrial-strategy> 2. <https://www.smm.co.uk/wp-content/uploads/sites/2/SMMT-CAV-position-paper-final.pdf> (page 17)

3. <https://waymo.com/apply/faq/> 4. The project considered forecast trips within Greenwich in 2025, but with an otherwise unchanged road and bus network

5. Further detail can be found in the MERGE Greenwich report on How AV ride-sharing can be implemented: www.mergegreenwich.com/city-compatibility-how-av-ride-sharing-could-be-implemented

Key findings

MERGE Greenwich research found there is evidence that autonomous vehicle (AV) ride-sharing is achievable and can add value to the city and consumers:

- **People are willing to use an AV ride-sharing service but concerns about sharing trips need to be addressed:** Customer research found 85% of respondents would be willing to use AVs, believing that the vehicles would be safe

and appropriately regulated by the time they were available as part of a public service. However only 46% said they would be willing to use a ride-sharing service regularly. Whilst this is still a significant number, the relative reluctance to share is underpinned by concerns about privacy, personal security and the social rules of being with strangers in a confined space with no driver. Women in particular had concerns. Public education, appropriate vehicle and service design as well as the option to have an on-board 'steward' should be considered as ways to overcome these concerns.

- **AV ride-sharing could account for nearly a third of all internal trips in Greenwich:** MERGE Greenwich modelling indicated 68% of all passenger trips⁶ could, in theory, be shared. However, when customer research findings about passenger willingness to use AV ride-sharing (mentioned above) were overlaid, it was found this new service could account for over a quarter (28%) of all trips. This suggests AV ride-sharing could become a significant part of the transport system.
- **AV ride-sharing could make travel more accessible:** Analysis showed AV ride-sharing services can address mobility gaps, particularly in poorly connected areas. In areas with low public transport accessibility levels (PTAL) this simulation found that an average journey time reduction of up to 53% can be achieved, compared to current journey times with existing public transport options. If the service is designed for maximum convenience (which comes at a higher price), simulation showed journey times can be reduced by as much as 74%.
- **AV ride-sharing could be used as a feeder for mass transport:** Simulations showed the average journey time to key transport hubs could be reduced by 43% compared to public transport (about 13 minutes for a journey which would take 22 minutes



6. This represents journeys which started within a 5-minute window and had similar pick-up and drop-off locations. This study was based on trips within the Royal Borough of Greenwich. More trips may be sharable in a wider geographic area.

by bus). This is the equivalent of a regular commuter saving 3.5 days per year in travel time⁷.

- **This service can be delivered in a way that makes sharing convenient:** By sizing the fleet appropriately, applying service level targets and optimising allocation and dispatch logic, simulations showed occupancy ranging between zero and five people. The highest occupancies are of relatively short duration during the morning and afternoon peaks. At other times of the day, the occupancy typically varied between one and three people across the minibus fleet (with vehicles that can carry up to eight people). This seems to indicate vehicles with a modest seat capacity are best suited for the types of service being considered.
- **It would allow car parks to be repurposed:** Simulation showed that private car usage does drop as a result of the introduction of an accessible convenient service. In the MERGE Greenwich simulation this caused a reduction in kms driven by private cars between 6% and 16%, depending on how the AV ride-sharing service was designed. This also led to a 38% reduction in trips that required parking, which means this valuable urban space could be repurposed for other uses.
- **Scale operation is important to accelerate the introduction of a new technology, achieve commercial viability and deliver a service that customers can trust:** Building the capability to operate a fleet, offer a complete passenger service and gain the operational experience required to guarantee customers have a good outcome is vastly expensive, complex and takes considerable time to get right. Cost-benefit modelling showed that achieving a positive cash flow and profitable service was very difficult unless there was an economy of scale of operation to build from.

Whilst our simulations and analysis provide evidence that the service is achievable and

could have a positive impact, the MERGE Greenwich project also highlighted a number of challenges to the vision and some unintended consequences:

- **More passengers will switch to AV ride-sharing from buses rather than cars unless services are priced appropriately:** MERGE Greenwich simulations showed a large shift from bus passengers (up to 34%) was the unintended consequence of providing a well-priced, on-demand and more direct service. However, when the price of the new service was increased, the impact on existing bus services was smaller (8% switched). The availability of the new AV ride-sharing service was not enough to see a wholesale switch of private car owners, with up to 14% switching. However, when car usage was penalised through higher parking fees, initial results suggested this could force a much higher rate of switching from private cars to AV ride-sharing.
- **Road congestion could increase unless external policies support switching from private cars:** Simulations showed that introducing a low-cost and highly convenient service alongside existing modes of transport could lead to mass switching from buses, which increased total vehicle kilometres by up to 57%. Pricing the AV ride-sharing service appropriately will need to be supported by external policies which increase the cost of motoring in order to encourage more switching from private cars. Unless this is achieved, the new fleet will increase the total kms and will naturally contribute to congestion.
- **Pricing models are still to be established to give the right return and ensure high demand:** Our simulations focussed on pay-per-ride models and differential pricing based on service quality and convenience levels, whilst trying to ensure mass-market appeal and avoid direct price competition with existing public transport. In addition

7. Based on making this journey twice a day, 260 working days per year

to this, it would be valuable to consider local and temporal elasticity of demand and the opportunity to have dynamic pricing to suit different segments. This could be extended to assess the impact of subscription models and of loyalty schemes. Beyond pricing for the transport service itself, there is also an opportunity to create ancillary revenue streams through mapping data, transport data and in-car services. Pricing and customer lifetime monetisation are key to making a new service viable.

- **The safety implications of AVs during the transition period are uncertain and will require a considered approach to implementation:** This project assumed the new AV ride-sharing service would be introduced alongside existing, driven modes of transport at the level of traffic forecast for 2025. Whilst it is widely acknowledged that over 90% of road accidents involve human error, no evidence exists that would allow meaningful conclusions to be drawn from the simulations about how the interaction between autonomous and human-driven vehicles would affect the number of collisions. Total vehicle kms increase under the MERGE Greenwich simulation but it is unclear if the probability of accidents would increase as a result.
- **Commercial viability is possible; however first-generation vehicles are likely to be expensive and labour costs cannot be eliminated:** First generation services will be costly to setup and operate, posing a challenge to profitability. Current cost estimates for autonomous vehicles range between three and five times greater than the price for an equivalent conventional vehicle. Some elements of a driver's role can be delegated to the vehicle but, to preserve customer experience and operational practicalities, other parts of the driver's role have to be delegated to kerbside or venue based support, the digital experience, contact centre support, mobile support and depot based support.

On-board assistance may also be required for some services such as those for the elderly or infirm, or to provide premium differentiation.

- **Environmental benefits will depend on the fleet and the level of switching from private cars:** The simulations utilised fully electric vehicles with zero tailpipe emissions but, unless these vehicles are charged from renewable sources and lead to a significant reduction in private car usage, the addition of a sizeable fleet could cause an increase in total road traffic, which could have the unintended consequence of raising CO₂ emissions.

Call to action

As we anticipate the arrival of self-driving vehicles on the streets of our cities, we have an historic opportunity to adopt this technology in an integrated and inclusive way which delivers environmental benefits, meets city objectives and makes travel easy and accessible for all citizens.

If introduced without the right framework for integration and synergy with existing transport modes, such a new service could have unintended consequences. It could lead to an increase in traffic and emissions. It could also manifest as an inequitable service which supersedes or competes with public transport.

To realise the benefits from Mobility as a Service and mitigate against unforeseen outcomes, Government could create a City Mobility Taskforce to set out the vision, strategy and goals for the introduction of AVs and ride-sharing services in cities.

The mandate for such a taskforce could include:

- Set out the vision, strategy and goals for the introduction of autonomous services
- Propose policies which encourage the right modal shifts

- Align the introduction of autonomous services with wider social, environmental and economic objectives
- Engage and educate the public on ride-sharing and autonomous vehicles
- Set out changes and guidelines for infrastructure planning and investment

The MERGE Greenwich project has signposted many of the next steps required by cities, governments, operators and automotive technology providers to deliver autonomous ride-sharing in a way that

can deliver benefits city-wide. In addition to the establishment of a City Mobility Taskforce, Appendix 1 includes a detailed set of recommendations for each of these audiences.

If all parties work together to plan, co-ordinate and deliver in an integrated fashion, ensuring new services feed existing mass-transport options, MERGE Greenwich concludes that autonomous vehicle ride-sharing could potentially have a huge, positive impact on the sustainability and growth of mobility in our cities.



2. Introduction

As urban populations expand, cities face the challenge of making sure the availability of transport keeps up with the increasing demand. New technologies, such as autonomous vehicles (AVs), and emerging business models, such as ride-sharing, are often cited as two ways to solve this mobility challenge.

The MERGE Greenwich vision was to develop a blueprint for an AV ride-sharing service, which integrates with public transport, hence 'merging' existing and new transport modes. The aim of this project was to explore how a new service could be designed and implemented to complement, rather than compete with, public transport.

A complex transport model and fleet simulation were developed, based on a target year of 2025, which positioned the AV ride-sharing service in the Royal Borough of Greenwich, London⁸. The project explored whether such a service could be viable within that time-frame and, if so, how it could be achieved. The research methodology, tools and lessons learnt by MERGE Greenwich can be applied to other boroughs and cities in the UK as well as overseas.

This report explores the drivers of demand for an AV ride-sharing service, considerations for mobility service providers looking to develop new offerings and the impact this service could have on the city and its citizens. A set of recommendations for government and industry are included, along with suggestions of further work, which could leverage the foundation developed by MERGE Greenwich.

MERGE Greenwich was a 12-month project, co-funded by government and industry. Global mobility services operator, Addison Lee Group, was proud to lead the consortium, which involved the significant expertise of Ford, TRL, Transport Systems Catapult, DG Cities and Immense Simulations.

By sharing the key findings, we hope the MERGE Greenwich project will help inform industry thought leaders, policy makers and the media about the opportunities for AV ride-sharing.

8. The model used trip forecasts for 2025 and assumed the road and bus network were otherwise unchanged.

2.1 What is MaaS and why is it relevant for the MERGE Greenwich project?

Mobility as a Service (MaaS) can be interpreted in different ways. For the purposes of this project, we assumed MaaS refers to transport being consumed as a service through an aggregator platform, which allows a customer to plan, book and pay for an end-to-end journey, involving multi-modes of transport in any geographical area. The vision for MaaS assumes a number of trips will be shared in order to increase the efficiency of the transport system as a whole. For this vision to be realised, new modes need to be developed in the context of a broader, integrated mobility system. This is why MERGE Greenwich aimed to develop a blueprint for AV ride-sharing which integrates with and 'feeds' the existing public transport network.

2.2 What exactly is autonomous vehicle ride-sharing?

One emerging transport mode is ride-sharing, a taxi-style service which groups passengers based on their origin and destination in order to give passengers the option of sharing a vehicle for their journey. MERGE Greenwich has developed a blueprint for such a service which uses a fleet of autonomous, or self-driving, vehicles. This is a mobility service which allows several passengers to share a vehicle if they have similar pick-up and drop-off locations. The service is enabled by specialised dispatch and allocation software, which optimises the route. MERGE Greenwich has assumed these vehicles are capable of 'SAE level 4' autonomy⁹, which means they do not require human intervention, and can operate in a large geo-fenced area.

2.3 Why are electric vehicles important in this context?

For AV ride-sharing to maximise benefits for the city, the fleet would need to be electric in

order to reduce emissions and help improve air quality. MERGE Greenwich simulations were based on the AV fleet being electric; however, in reality, this will require significant charging infrastructure investment which is discussed in a separate report: *City Compatibility: How AV ride-sharing could be implemented*¹⁰.

2.4 Why did MERGE Greenwich target 2025?

Autonomous vehicle ride-sharing services are already being planned in the US¹¹ and these vehicles could be commercially available from 2021, according to announcements from a number of large car manufacturers. Ride-sharing is already an emerging service model. With these factors in mind, MERGE Greenwich chose 2025 as the year in which AV ride-sharing could, theoretically, be widely available, accepted and used in major, complex urban centres. Basing the simulation in this year allowed MERGE Greenwich to evaluate the AV ride-sharing service as if it were an integrated part of the mass transport system. It is, nonetheless, important to recognise there will need to be a transition period to reach this scenario and careful consideration must be given to how that transition period is planned for and delivered.

2.5 Will autonomous vehicle technology be safe?

MERGE Greenwich set out to evaluate a business model which could use autonomous vehicle technology, rather than to investigate the autonomous technology itself. Many other organisations and projects are focusing on AV technology development and MERGE Greenwich aims to support these initiatives by accelerating the route to market for this technology as soon as it is market ready. There is a common assumption that AV technology will be held to a higher standard than human drivers and that AVs will only legally be allowed to operate when they have been regulated and proven to be safe. For

9. <https://www.smmmt.co.uk/wp-content/uploads/sites/2/SMMT-CAV-position-paper-final.pdf> (page 17)

10. www.mergegreenwich.com/city-compatibility-how-av-ride-sharing-could-be-implemented

11. <https://waymo.com/apply/faq/>

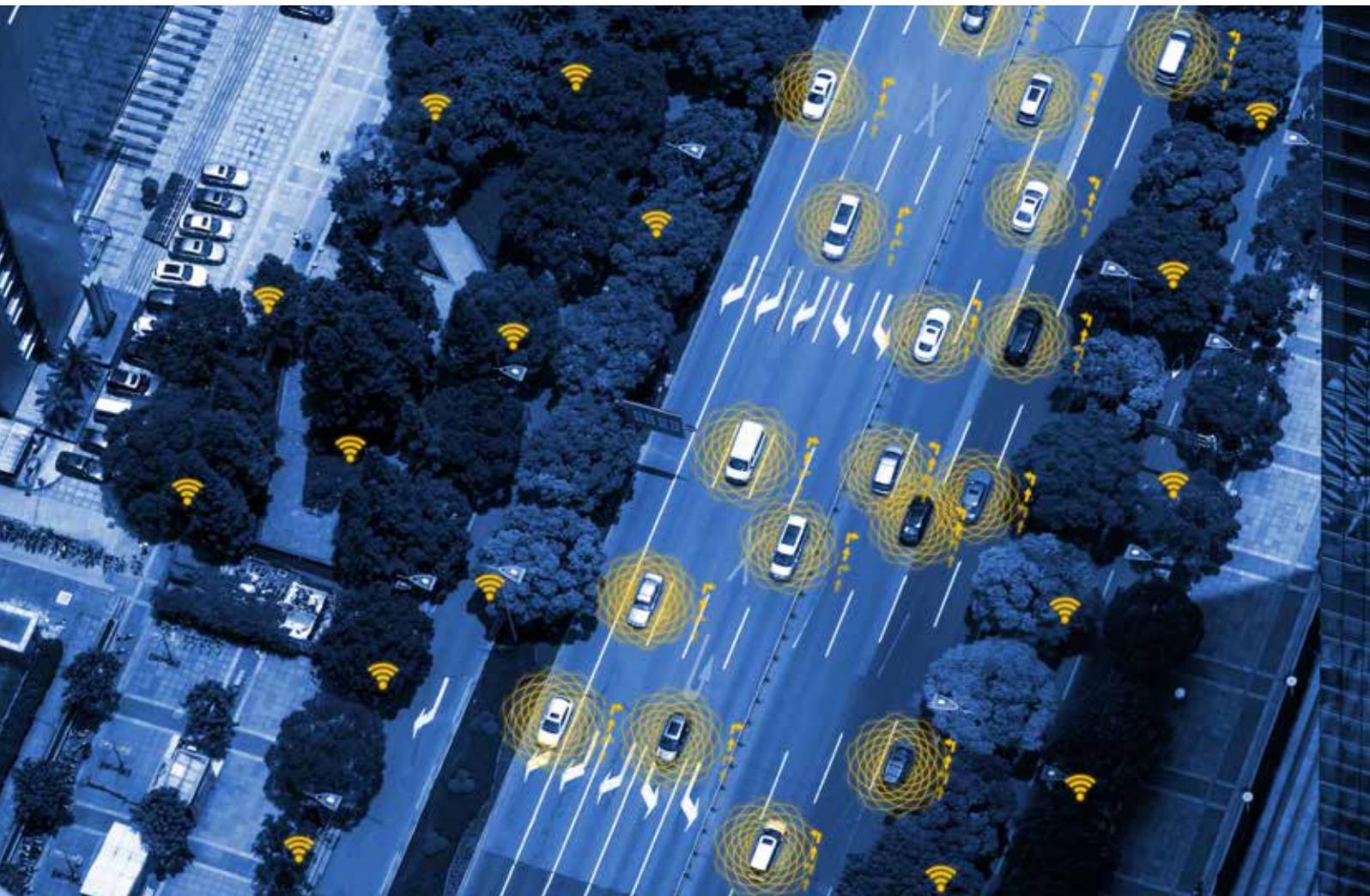
these reasons, the MERGE Greenwich project assumed AV technology will be safe for use by the modelled year of 2025.

2.6 Why is it important to develop a blueprint for AV ride-sharing now?

AV technology and ride-sharing are expected to play an important role in optimising the transport network by tackling recurrent traffic issues in cities, namely congestion, pollution and accessibility. To understand how AV ride-sharing could fulfil this role it is important to understand every aspect of the service, the ecosystem in which it will operate, the impact the new service will have on the ecosystem and vice versa. It is also essential for government organisations to understand these elements in order to plan

ahead for new developments, regulation and public transport services.

No organisation or government would implement a new product or service without rigorous testing and analysis to understand the potential impact as well as the commercial viability. The MERGE Greenwich project is the first of its kind to develop and test a blueprint for AV ride-sharing, particularly because it involved expertise and input from such a diverse range of organisations, including a global service operator, vehicle manufacturer, local borough and advanced transport modelling. This breadth of input has enabled the consortium to design and evaluate a number of service blueprints to see how AV ride-sharing could interact with current transport modes, and so enhance mobility.



3. Methodology and deliverables

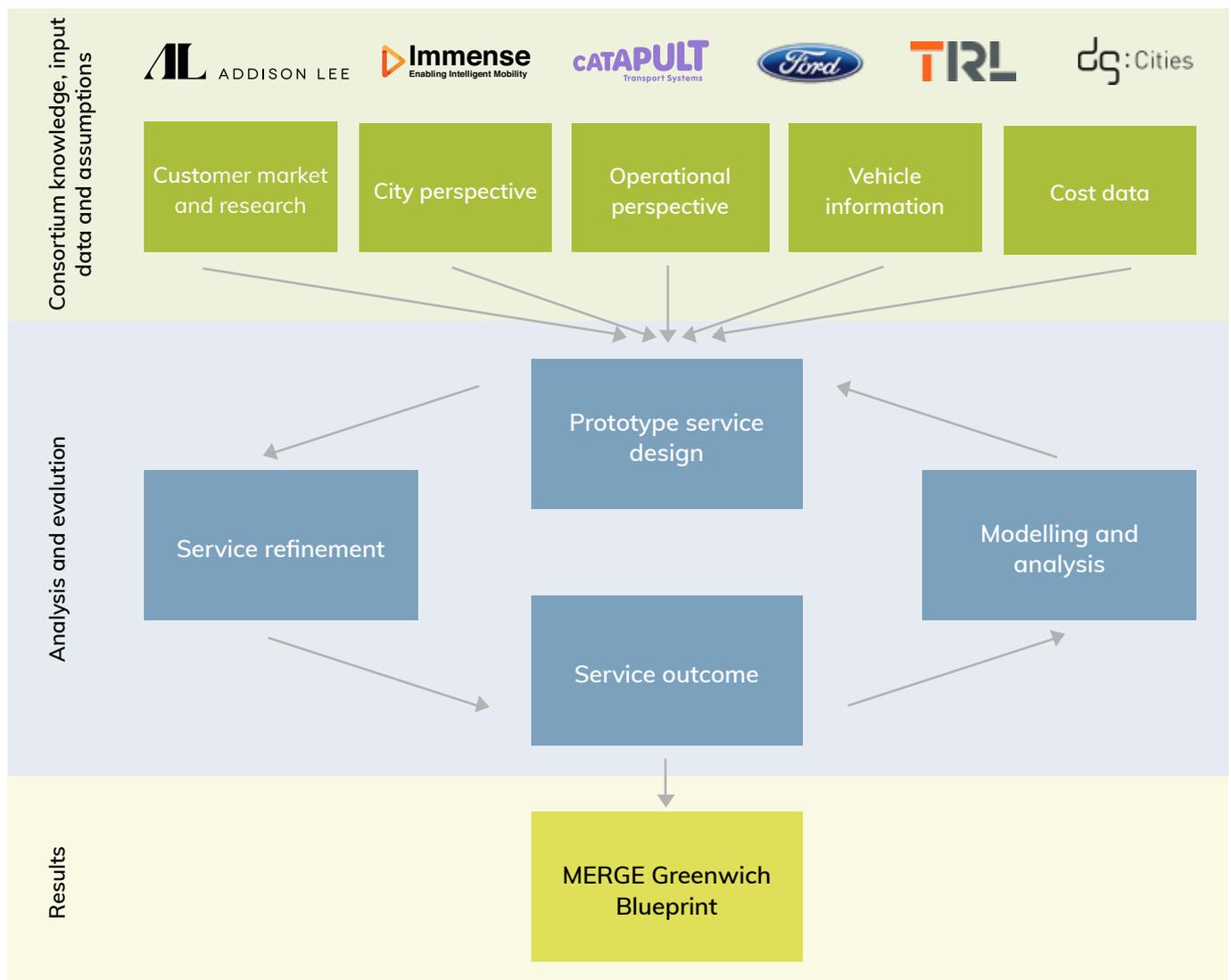
MERGE Greenwich research involved expert input from all consortium members, a review of available literature on the topic, innovative transport demand modelling, complex fleet simulation, commercial evaluation and impact analysis to assess the costs and benefits of implementing such a service.

The transport model focused on trips within the Royal Borough of Greenwich, taking current transport modes and journey data, and overlaying an AV ride-sharing service.

This Borough experiences a wide range of transport characteristics, from major roads to new areas under construction, from local communities to world-renowned attractions. The breadth of these characteristics means the lessons learnt from this simulation can be applied to other urban areas, boroughs and cities in the UK as well as abroad.

A summary of the process followed is given in Figure 2 below.

Figure 2: MERGE Greenwich project overview



3.1 Consortium approach

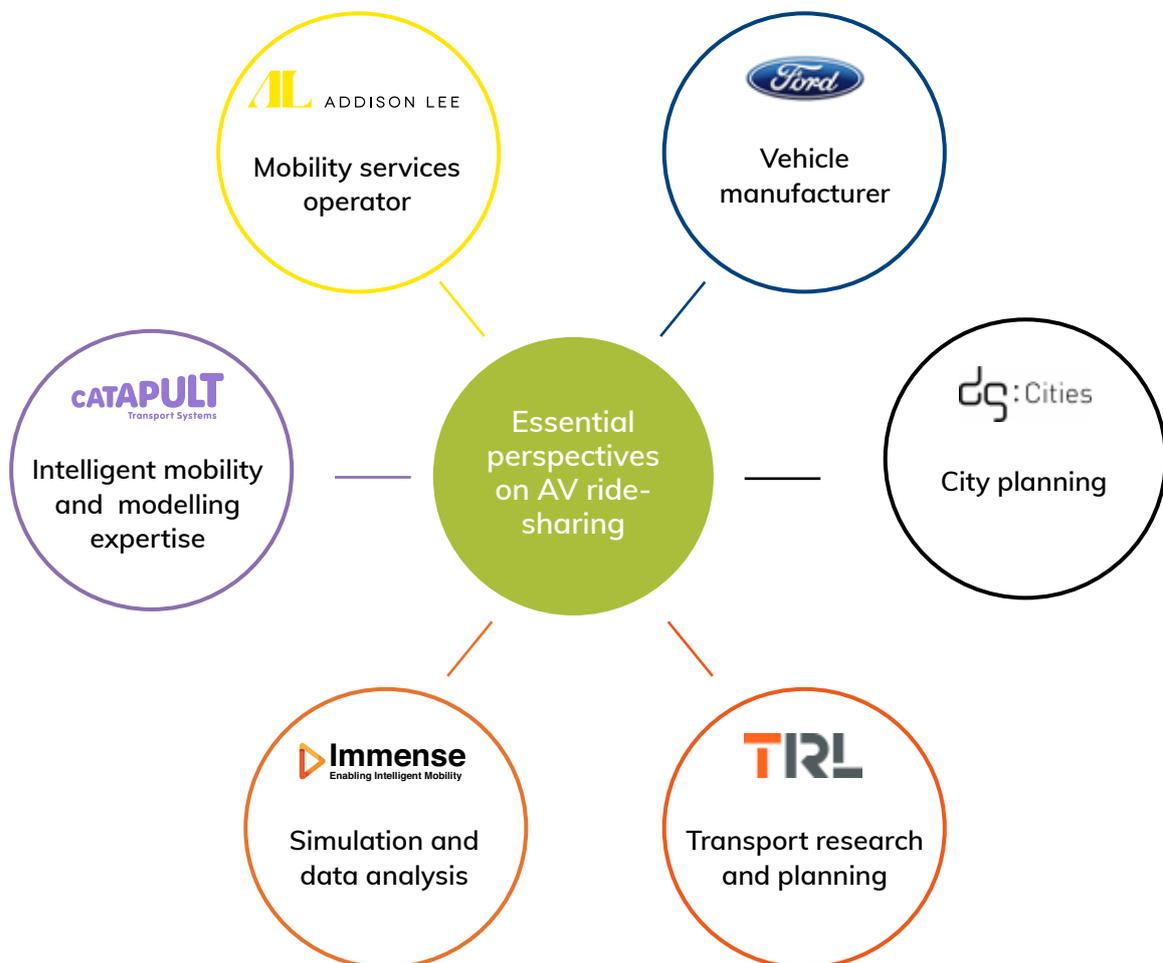
The complementary backgrounds of the consortium partners provided a valuable breadth of input, which greatly supported the development of this research.

- Addison Lee Group brought its experience as a global mobility service provider to business and consumers, along with real world commercial knowledge of operating the largest private hire fleet in Europe
- Ford, a global vehicle manufacturer engaged in developing AVs and mobility solutions, supported the project by investigating requirements and likely costs of vehicles which would meet the demands of an AV ride-sharing service
- DG Cities contributed the city perspective; this knowledge of city challenges helped

the project partners understand how an AV ride-sharing service should be deployed, considering the complex urban environment and the needs of cities

- TRL developed methods for assessing the impacts of the hypothetical blueprints on the transport system
- Transport Systems Catapult brought their transport modelling expertise to determine the potential demand for AV ride-sharing and the corresponding impact on other modes of transport
- Immense Simulations developed an advanced fleet simulator that used discrete optimisation methods to estimate the numbers of each different type of vehicle required to operate such as service

Figure 3: The breadth of expertise which underpinned the MERGE Greenwich project



3.2 What MERGE Greenwich set out to achieve

To evaluate whether new modes of transport could contribute to the MaaS vision, MERGE Greenwich aimed to develop a blueprint for an AV ride-sharing service which integrates with public transport systems in a geofenced area covering the Royal Borough of Greenwich. The consortium tested the impact of implementing such a service to understand whether this new mode could offer a positive contribution towards delivering the MaaS vision of making cities greener, more efficient and more accessible.

In particular, MERGE Greenwich asked of AV ride-sharing:

- Can a significant number of trips be shared?
- Will people be willing to use an AV ride-sharing service?

- Can ride-sharing services be optimised for passenger convenience?
- Will modal shift to AV ride-sharing take passengers away from public transport?
- Will AV ride-sharing deliver social benefits?
- Will AV ride-sharing be commercially viable?

3.3 Deliverables and assets developed by MERGE Greenwich

MERGE Greenwich delivered a number of firsts, from research to transport modelling, simulation tools, vehicle requirements and business model design. Other organisations and government bodies are encouraged to contact the consortium members if they would like to understand how they can leverage this knowledge and these new tools.



3.3.1 Research

Customer research

MERGE Greenwich conducted the first known customer research¹² dedicated to understanding customer attitudes towards an AV ride-sharing service, rather than just AV or ride-sharing in isolation. An online survey and focus group interviews were led by DG Cities, providing quantitative as well as qualitative data. This research enabled MERGE Greenwich to develop five key personas, which vary in terms of gender, age, income, motivations and concerns. These personas were incorporated into the transport model and informed the service design.



City compatibility research

Two city compatibility reports¹³ were published as part of the project to outline the mobility gaps which AV ride-sharing could address (led by DG Cities) and considerations for the implementation of AV ride-sharing (led by TRL). These reports aim to inform industry and government leaders about the need for forward planning to ensure the new technology and services can be introduced effectively to maximise benefits for the city and its residents.



3.3.2 Customer experience design

Digital customer experience development

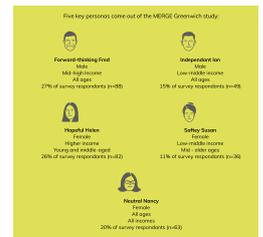
Leveraging Addison Lee's expertise in app interface design and user experience, the MERGE Greenwich consortium explored the app elements



which would impact the uptake of AV ride-sharing. The key to successful integration of the new services was linked to 'gamification' in the app, to encourage passengers to choose modes which would improve the efficiency of the transport network as a whole as well as minimising their journey time.

Personas and tiers of service developed

Based on the customer research, MERGE Greenwich developed 'personas' to group types of passengers according to their age, gender, income and willingness to use AV ride-sharing. This information was combined with Addison Lee's customer service knowledge in order to develop tiers of service which would meet a variety of customer needs. These personas and tiers of service were applied to the transport modelling in order to produce an accurate reflection of likely demand for the service.



Blueprint design



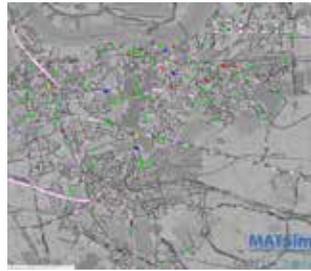
Three distinct blueprints (AV ride-sharing services) were designed to specify the input parameters for the transport modelling. Each service aimed to achieve different objectives from operating an AV ride-sharing service. The blueprints differed by fare and service level criteria, such as waiting time and detour time. The first blueprint aimed to optimise the service for mass availability and accessibility; the second prioritised customer service and convenience, at higher cost; and the third aimed to combine attributes of both. These blueprints and their impact are discussed in detail later in this report.

12. <https://mergegreenwich.com/2018/04/10/customer-attitudes-av-ride-sharing/>
13. <https://mergegreenwich.com/category/news/>

3.3.3 Modelling and analysis

Advanced transport demand modelling

TSC developed a sophisticated agent-based model¹⁴ which was used to predict the potential use of AV ride-sharing, bus and private cars for trips throughout the day in the Borough of Greenwich. The model was the first of its kind and used the National Trip End Model (NTEM) combined with demographic data for Greenwich to estimate the base transport demand for 2025 (assuming that bus services remain unchanged). The choice of transport mode for each trip was estimated using parameters such as the monetary costs to the user, the value of time and a measure of willingness to use AV ride-sharing obtained from the MERGE Greenwich customer research¹⁵.



The predicted demand for AV ride-sharing was passed to an advanced fleet simulator which was responsible for optimising how the fleet would serve this demand.

Advanced fleet simulation

A separate and novel fleet simulation model was developed by Immense Simulations using advanced discrete optimisation techniques to improve the allocation of AV ride-sharing vehicles to the trips predicted by the demand model. To meet the predicted demand, the simulation estimated how many different vehicle types were required in order to achieve the specified waiting time, detour time and trip fulfilment.



Traffic speed data for Greenwich was used to calculate realistic journey times for each modelled vehicle trip. This simulation also

calculated the level of sharing and vehicle utilisation achieved by each service, and the distance travelled by the AVs when carrying passengers and when running empty between trips.

It was necessary for the demand model and fleet simulation to 'iterate' with each other until they converged on a stable level of demand that could be met for a given fleet size and composition of vehicle types. This was a complex process which required bespoke programming to integrate the two systems and develop co-simulation which could match supply (of vehicles) with demand (for trips).



Autonomous vehicle requirements and cost assessment

A vehicle analysis was carried out by Ford to define the vehicle requirements such as powertrain type, range, number of seats and charging time needed for AVs to operate in a ride-sharing model. A specific tool was developed by Ford, which allowed consortium members to select different vehicle types and understand the impact this had on vehicle requirements as well as cost.

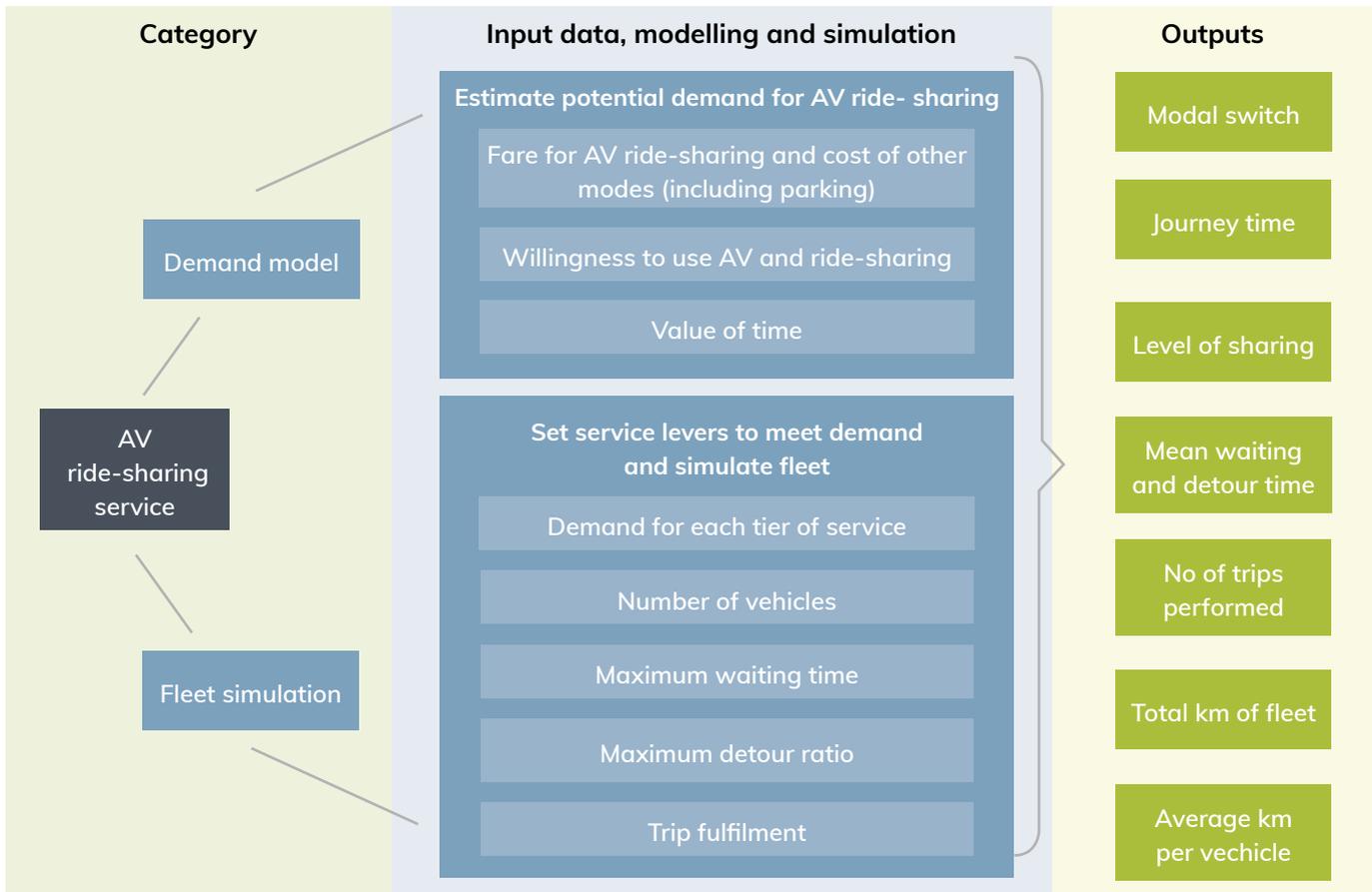
CUCV		MINIBUS	
INPUT	200	INPUT	200
Vehicle type	200	Vehicle type	200
Vehicle range	200	Vehicle range	200
Vehicle seats	200	Vehicle seats	200
Vehicle powertrain	200	Vehicle powertrain	200
Vehicle charging time	200	Vehicle charging time	200
Vehicle cost	200	Vehicle cost	200
Vehicle maintenance	200	Vehicle maintenance	200
Vehicle insurance	200	Vehicle insurance	200
Vehicle depreciation	200	Vehicle depreciation	200
Vehicle operating cost	200	Vehicle operating cost	200
Vehicle total cost	200	Vehicle total cost	200
OUTPUT	200	OUTPUT	200
Vehicle utilisation	200	Vehicle utilisation	200
Vehicle distance	200	Vehicle distance	200
Vehicle time	200	Vehicle time	200
Vehicle cost per trip	200	Vehicle cost per trip	200
Vehicle cost per hour	200	Vehicle cost per hour	200
Vehicle cost per mile	200	Vehicle cost per mile	200
Vehicle cost per passenger	200	Vehicle cost per passenger	200
Vehicle cost per passenger mile	200	Vehicle cost per passenger mile	200
Vehicle cost per passenger hour	200	Vehicle cost per passenger hour	200
Vehicle cost per passenger mile hour	200	Vehicle cost per passenger mile hour	200

Having tested a number of different configurations for the four chosen vehicle types, the resulting vehicle parameters were fed into the fleet simulation and the business

14. Agent-based models simulate entities in the system individually, in this case the choice of mode by each traveller. This allows for individualised decision making which can potentially capture people's travel behaviour more realistically than conventional aggregated modelling that considers large groups.

15. <https://mergegreenwich.com/2018/04/10/customer-attitudes-av-ride-sharing/>

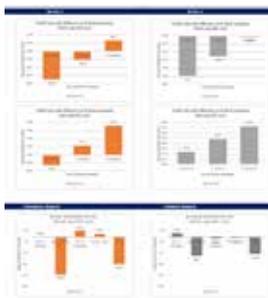
Figure 4: Advanced transport modelling and fleet simulation produced outputs which were used to assess the impact of an AV ride-sharing service



cost model in order to understand the impact on the service as a whole.

Business case and cost/benefit analysis

Whilst cost/benefit analyses are nothing new, MERGE Greenwich was the first to combine the insights from such a diverse range of organisations, as well as complex modelling and simulation, to develop a detailed business case for an AV ride-sharing service set in Greenwich in 2025.



Using its expertise in operating a fleet commercially, Addison Lee developed a cost and revenue model to understand whether operating an AV ride-sharing service could be

commercially viable. This model considered operational costs and revenues, estimated costs of vehicles and charging facilities, and the business support functions needed to run such a service. From this, and with the quantitative inputs and assumptions from consortium members – in particular the modelled vehicle numbers required, distance travelled and the passenger demand – the MERGE Greenwich business model was developed to determine the commercial viability of each AV ride-sharing blueprint.

3.3.4 Modelling assumptions

When interpreting the findings from MERGE Greenwich it is important to bear in mind that all models involve a degree of simplification and initial assumptions. In particular, the

MERGE Greenwich models assumed that transport conditions in 2025 were 'business as usual' forecasts, with AV ride-sharing services overlaid on top. This meant bus services were unchanged in their availability or price. Trips were only modelled within the Borough of Greenwich. Where longer distance rail trips were identified in the transport demand model, only the legs to and from the station within Greenwich were considered.

The model used values of time based on the Department for Transport's Transport Analysis Guidance (TAG)¹⁶. The willingness to ride-share, derived from MERGE Greenwich's qualitative research, was also very influential in the model. The transport demand model did not take account of cycling or walking. Although time was allowed for bus passengers to walk to the bus stop, car journeys were assumed to be made door-to-door, with no walking time assumed either for parking private cars or for meeting an AV ride-sharing service. Car parking was assumed to be always available with no additional time required to find a

space. Trips were considered individually: no trip-chains were formed, there were no group trips and car passenger trips were not linked to driver trips. Multi-modal trips (e.g. park and ride) were not simulated and total demand for trips was assumed to be static, i.e. the model did not assess any additional demand which might be generated if a new service were introduced.

Finally, it is worth recognising that this research was based on data available at the time and a section on 'further work' (Appendix 2) indicates where additional research would be valuable, as and when new data becomes available.

In order to test the impact of an AV ride-sharing service, MERGE Greenwich developed and analysed three service designs or 'blueprints'. These blueprints specify different fares and service levels, which were informed by learnings from the project regarding the demand for AV ride-sharing and how the service could be supplied. This section of the report shares those findings, introduces the three blueprints and highlights some of the major factors driving their design.



16. <https://www.gov.uk/guidance/transport-analysis-guidance-webtag>

4. Blueprint

4.1 Demand for AV ride-sharing

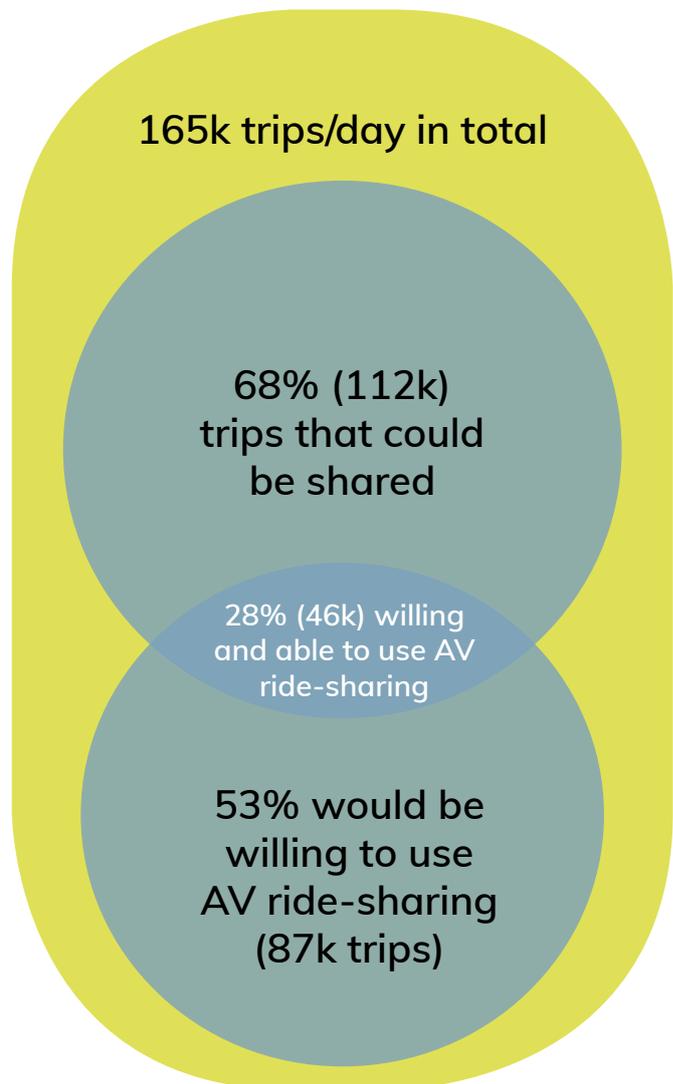
Understanding customers' expectations, motivations and concerns around AVs and ride-sharing is critical for a provider to offer a commercially successful AV ride-sharing service and drive the development of mobility services in the future. The impact these core drivers of demand could have on the service and how they were applied within the MERGE Greenwich modelling are explained below.

4.1.1 Actual demand for services differs considerably from the theoretical demand

It is helpful to begin by understanding the theoretical potential for ride-sharing, based on the proportion of all trips which have similar origins, destinations and start times.

The total number of daily trips which start and end within Greenwich is forecast to be over 165,000 by 2025. The MERGE Greenwich transport demand model was able to show that, in theory, 68% (112,000) of these trips could be shared because they start within a five-minute time window and have similar pick-up and drop-off points¹⁷. This provides an indicator of the maximum number of trips that could be shared if there were no other constraints. It is important to note that many of these 'sharable' trips are already shared because they are undertaken by public transport.

Taking this a step further, MERGE Greenwich customer research (discussed in more detail below) indicated that of all the daily trips in Greenwich, passengers are willing to use an AV ride-sharing service for up to 28% (46,000) of these journeys. In essence, this sets the limit for the maximum uptake of AV ride-sharing but, as it accounts for nearly a third of all trips, it is a strong indicator that AV ride-sharing could become a significant part of the transport network if it were introduced.



4.1.2 Willingness to adopt autonomous vehicles differs from the willingness to share

To get a more detailed view of likely customer adoption, MERGE Greenwich researched attitudes towards AVs and ride-sharing separately, as well as assessing willingness to use an AV ride-sharing service. This research revealed the willingness to use AVs differs from the willingness to use a ride-sharing service. Different types of concerns and motivations were evoked by each aspect of the service.

¹⁷. <https://www.gov.uk/guidance/transport-analysis-guidance-webtag>

Transport modelling indicated 68% of all trips could, in theory, be shared, yet overlaying customer research indicated passengers would be willing to use AV ride-sharing for 28% of all trips.

The overwhelming acceptance of AVs (86% said they would be willing to use an AV in future) was underpinned by the belief that regulators would not allow a vehicle on the road until it had been rigorously tested. Some, particularly men with a higher income¹⁸, also expressed an eagerness to experience the new technology. Research participants mentioned the uncertainty about AVs coexisting with other road users during the transition period, but it was assumed any risk during this time would be mitigated by regulatory and traffic management measures.

The relative reluctance to ride-share (45% were willing to use a ride-sharing service once or twice a week) was linked to the 'social rules' being different in a confined space, such as a car, compared to a larger public space, such as a bus or tube carriage. In a confined space it was unclear what level of social interaction would be expected or whether passengers would have the opportunity to exit the vehicle if they were uncomfortable around others. The idea of sharing a ride with strangers also raised concerns related to privacy and personal security, particularly among women.

However, MERGE Greenwich identified ways in which these concerns could be overcome:

- **Purpose-designed vehicles:** The design of the autonomous vehicle could overcome concerns and help encourage ride-sharing in future. By configuring the vehicle to provide sufficient personal space, large windows to connect passengers to the outside world, real time information and an emergency call button, the purpose-designed space could allay fears and encourage the uptake of ride-sharing. Using technology to connect passengers to customer support will be an important way to reassure them of personal safety and ensure that only bona-fide passengers can get into the AV.
- **Have a safety steward on board:** Having a steward on board would greatly alleviate these concerns and increase demand among passengers who want personal security, particularly women under 45 years old. Whilst remote monitoring could go some way to addressing these concerns, the option to choose a service with an on-board steward could provide important benefits to certain passengers. This option would be valued by elderly or less able passengers and could reduce the need for specialised services, such as Dial-a-Ride, which are heavily subsidised.
- **Offer fixed-route services:** Offering a shuttle-type service with a fixed route and destination would also increase the perception of safety and may be more popular than a shared service with flexible routes.
- **Use gamification to influence modal choice:** The booking app can be used for more than simply providing standard journey information. By including information which allows passengers to score 'points' for choosing a particular mode, the service provider may be able to influence customer behaviour which could improve efficiency of the system as a whole, and ultimately reduce journey times in the area. For example, these

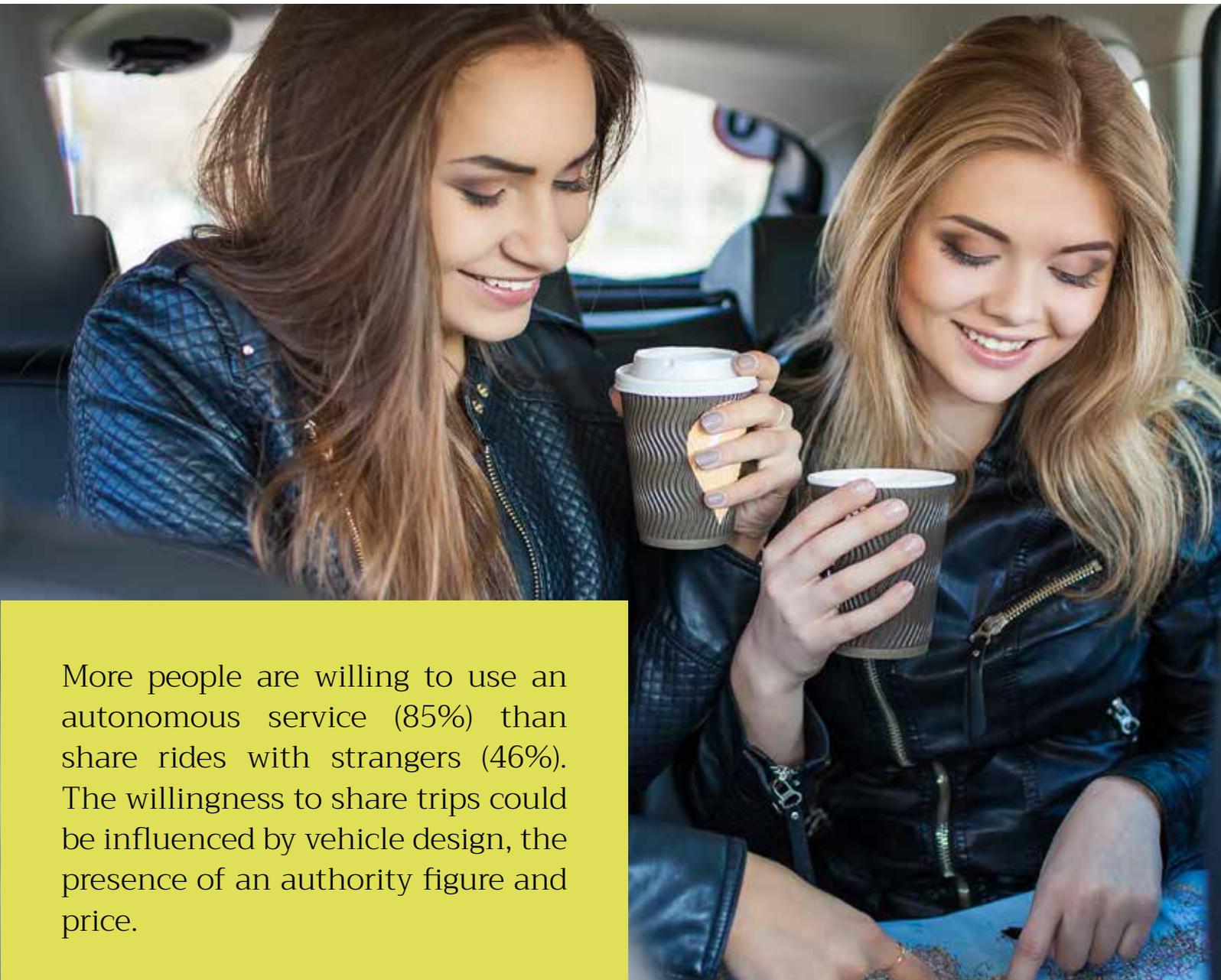
18. Further detail on personas of likely AV ride-sharing passengers can be found in the MERGE Greenwich customer research report: <https://mergegreenwich.com/wp-content/uploads/sites/13/2018/04/MERGE-Greenwich-Consumer-attitudes-to-AV-ride-sharing-3.pdf>

points may offer 'rewards' to encourage an increase in the amount of walking included in an end-to-end journey, or to opt for ride-sharing instead of a solo trip.

- **Price services to compensate for sharing:** MERGE Greenwich research indicated AV ride-sharing customers would accept an increase in journey time of between 6 and 15 minutes to collect additional passengers in return for a 30% reduction in fare, compared to a normal taxi ride¹⁹.

4.1.3 Likely users of AV ride-sharing services

MERGE Greenwich's customer research report *Customer attitudes to AV ride-sharing*²⁰ classified people according to their attitudes towards AV ride-sharing and developed personas for each group based on age, gender and income. Each persona indicated a different level of willingness to use AVs and ride-sharing, which was used as an input to the demand model.



More people are willing to use an autonomous service (85%) than share rides with strangers (46%). The willingness to share trips could be influenced by vehicle design, the presence of an authority figure and price.

19. <https://mergegreenwich.com/wp-content/uploads/sites/13/2018/04/MERGE-Greenwich-Consumer-attitudes-to-AV-ride-sharing-3.pdf>
20. <https://mergegreenwich.com/wp-content/uploads/sites/13/2018/04/MERGE-Greenwich-Consumer-attitudes-to-AV-ride-sharing-3.pdf>

This research reiterated that early adopters of an AV ride-sharing service are likely to be passengers who currently use taxis or private cars. The key motivation for taxi-users to switch mode would be to experience the exciting new AV technology, along with an expected reduction in price. However, for private car users (drivers and passengers) the key motivation would be to avoid the cost and inconvenience of parking (linked to time lost searching for a parking space). These customers are expected to opt for the Standard or Executive services, as outlined below.

For other passengers, the convenience of an AV ride-sharing service which offers flexible pick-up and drop-off locations could improve accessibility, especially for those who currently live/work in a transport black spot or have physical difficulty using public transport.

4.1.4 Demographic drivers of demand

The customer research showed that time, convenience, safety and acceptable price are recurring features that customers value, regardless of their demographic type. These are important drivers of demand for transport more generally. Social responsibility emerged as an additional motivator for some when considering using an AV ride-sharing service.

Elderly passengers indicated an AV ride-sharing service could be of particular benefit to them, in terms of increased accessibility, saved time and increased comfort.

However, one demographic group in particular had different drivers of demand for AV ride-sharing. Elderly people have other needs and, therefore, other drivers of demand. Accessibility and comfort were noted as particularly important features for this group and a new transport mode must respond to these needs. A reliable on-demand service which enables door-to-door journeys, offers personalised assistance on board, and uses vehicles with special facilities, would benefit this category of customer in terms of time saved and increased comfort.

4.1.5 Geographic drivers of demand

MERGE Greenwich's mobility gap report²¹ concludes that an AV ride-sharing service could respond effectively to the mobility gaps in current public transport, particularly by providing a solution in poorly connected areas.

AV ride-sharing could offer a flexible, on-demand, door-to-door service which enhances the connectivity to nearby transport hubs. By offering the advantages of greater convenience, reduced cost and reduced journey time, AV ride-sharing could provide a relatively swift and low-cost opportunity to scale up transport in certain areas, without the need to invest in long term and costly solutions such as a new tube station. This solution would also help encourage those who currently use private cars to switch mode, by offering the same level of convenience but at a lower cost, with a shorter journey time and without the inconvenience of needing to find a parking space.

4.1.6 Pricing as a determinate for demand

Price influences demand for AV ride-sharing, as it does for any mode of transport. The MERGE Greenwich AV ride-sharing service is designed to integrate with public transport. This means journey planning, booking and payment methods will need to be integrated

21. <https://mergegreenwich.com/city-compatibility-how-av-ride-sharing-could-address-mobility-gaps>

Customer research indicated early adopters of AV ride-sharing would most likely be current taxis users and private car owners, motivated by eagerness to experience the new technology, an anticipated reduction in price and greater convenience.



and price points should be set relative to other modes of public transport, in order to complement them rather than compete with them.

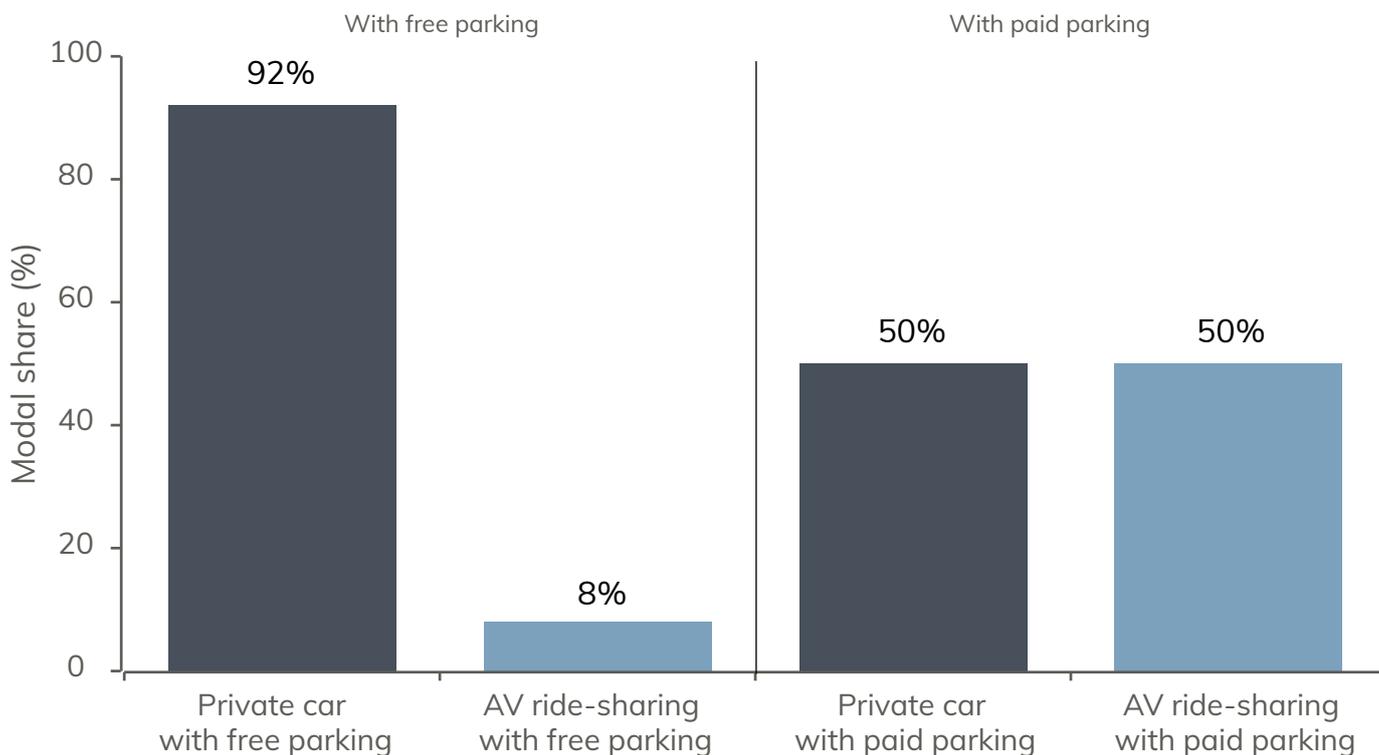
Sensitivity tests of the MERGE Greenwich simulations showed that two pricing factors had a particular impact on demand: (1) the minimum fare applied to AV ride-sharing and (2) the parking costs (and inconvenience) experienced by private car users.

Applying a minimum fare to the AV ride-sharing service significantly impacted the modal switch. For instance, increasing the

minimum fare by one pound from £5 to £6, resulted in a 23% drop in demand.

For private car users, being able to avoid the cost (and inconvenience) of parking was a strong driver of demand for AV ride-sharing. Figure 5 illustrates how car users' demand for AV ride-sharing increases (from 8% to 50%) when they are required to pay for parking. This indicates that demand for AV ride-sharing could be particularly high in areas where parking is limited/expensive.

Figure 5: The introduction of parking costs increased demand for AV ride-sharing from 8% to 50%



As MERGE Greenwich aims to develop a service which complements, rather than competes with, public transport, it is important to design a service which balances the drivers of demand outlined above. The next section of this report discusses how this can be achieved.

Increasing parking costs can lead to a significant shift to AV ride-sharing from private car users. Applying a minimum fare and setting flat fares at more than double bus fares reduces switching from public transport.

4.2 Service design to meet demand

Taking drivers of demand into consideration, alongside broader research results, revealed the need for a variety of transport services to be developed. The MERGE Greenwich report on *City Compatibility: How AV ride-sharing can address mobility gaps* outlined the types of service which could be required as:

- **Basic, cost-effective shared services with wider coverage**, with or without assistance on board for elderly people or those with mobility issues
- **Low cost, on-demand shared services with wider coverage** enabling faster, more direct connections between neighbourhoods
- **Combination of the above with new, faster 'arterial' services** linking major travel destinations in the north and south of the Borough

- Flexible, on-demand services to match the convenience of private vehicles but at a lower cost to the customer

Taking these demands into consideration and accounting for customer segmentation, MERGE Greenwich developed four tiers of

service which could fulfil consumer needs for ride-sharing. Each tier is differentiated in terms of price, convenience, and the level of sharing supported. Vehicles specified are Level 4 autonomous, which are fully self-driving for trips within the geo-fenced area.

Service name	Description	L4 autonomous vehicle
<p>Minibus service</p>	<p>This service targets groups of several people or families, as the vehicle can carry up to eight people. It could also be used for regular commuters who frequently require a shuttle-type service on a particular route. It is not anticipated that this vehicle would have a steward on board but, as with all AV ride-sharing vehicles, it will be possible to contact customer service via the app in case of emergency. Because this vehicle is the largest and capable of the greatest level of sharing, the price to the passenger will be lowest of all the service tiers.</p>	 <p>Example vehicle for the Minibus service (based on the current Ford Transit)</p>
<p>Assist service</p>	<p>This service caters for people with reduced mobility, e.g. disabled people or elderly passengers. This vehicle will be designed with easy entry/exit for wheelchair users and a steward/chaperone will be on board in order to assist passengers in and out of the vehicle. It will have more space inside and a large boot for any mobility aids (e.g. a wheelchair or walking frame) to be stored. Passengers with luggage or pushchairs may also opt for this service if they required assistance provided by the steward. Providing such a personalised and human service means the 'Assist' service is more expensive to operate than the other tiers and may require a subsidy to support independent living.</p>	 <p>Example vehicle for the Assist service (based on the current Ford Tourneo Connect)</p>
<p>Standard service</p>	<p>This service offering is expected to attract the largest number of customers from the target base, and therefore to be the most important service of the portfolio in terms of scale. In the MERGE Greenwich simulation this vehicle caters for four passengers, but in theory the service provider could choose to reserve one seat for an on-board steward. The price for this service would be comparable with a low-cost taxi service.</p>	 <p>Example vehicle for the Standard service (based on the current Ford Galaxy)</p>
<p>Executive service</p>	<p>This service offers a premium vehicle with four seats, a luxury interior design and more space in the car as well as in the boot. The vehicle will be equipped with the latest in-car technology and offer free WiFi. This service targets business passengers and those who prefer to travel in a higher specification of vehicle and enables the passenger to choose whether he or she travels alone or is open to ride-sharing. The journey price will be higher than the 'standard' service but can be reduced if the passenger is open to ride-sharing, regardless of whether other passengers join the journey or not. Operators could choose to offer an on-board steward/concierge with this tier of service but, for the purposes of MERGE Greenwich, we have assumed this is not available.</p>	 <p>Example vehicle for the Executive service (based on the new Ford Edge)</p>

Providing a range of service options, at different price points and with different attributes, will be essential to maintain customer preferences and choice. This will be fundamental for a mobility services provider to grow and maintain a loyal customer base.

4.3 Demand fulfilment

When developing an AV ride-sharing service, the operator can make a number of decisions which directly impact the supply side of the service to meet demand. All of these 'levers' have an impact on each other and the aim is to balance each one to ensure the service meets customer, city and operator needs. As with any transport service, particularly a ride-sharing service, the level of vehicle occupancy has a huge impact on the commercial viability as it ensures each asset (vehicle) is as highly utilised as possible. This can also help achieve city objectives by reducing the number of vehicles required on the road, so it is fair to assume that any ride-sharing service would aim to optimise the occupancy level.

This section of the report highlights the key supply decisions which operators will need to make and indicates the choices which were made for the purposes of the MERGE Greenwich blueprints.

4.3.1 Service levels

The customer experience is determined by the service design and delivery. This includes targets which are set for the service as well as 'rules' which are imposed on the fleet in order to optimise efficiency. The two key ways in which the service design influences the supply are:

- **Service levels:** The service levels are driven by three factors: (1) the maximum waiting time (2) the maximum detour

time which a customer will experience when other passengers are picked up or dropped off and (3) service fulfilment.

If targets for these times (1 and 2) cannot be met by the service, a message will need to be sent to the customer stating that their request cannot be fulfilled and they will be directed to use their current mode of transport to complete their journey. The service fulfilment target (3) therefore indicates whether the fleet is large enough to cater for demand.

The service level may be set higher for services which aim to achieve a greater degree of convenience. For example, one of MERGE Greenwich's blueprints aims for passengers to experience shorter waiting and detour times, but they will be charged a higher price for the increased level of service.

- **Tier switching within the fleet:** A fleet which uses different vehicles for different service offerings may allow 'tier switching' in order to increase the utilisation of the fleet and reduce the overall fleet size. In practice, this means customers who request a standard vehicle may 'get lucky' and be transported in a vehicle from a more premium service if it means the fleet as a whole can fulfil that trip request more efficiently. MERGE Greenwich considered that passengers could also be offered a lower grade vehicle in peak times in order to ensure they reached their destination, if a vehicle in the selected tier was not available.



4.3.2 Fleet sizing and vehicle choices

For the purposes of this project, MERGE Greenwich assumed autonomous vehicles will be fully tested, safe and ready for roll-out by 2025.

The size and specification of the fleet are key determinants of supply, as they influence the customer experience as much as the commercial viability of the service. For example, an oversized fleet may mean customers don't wait long for a trip but this could also lead to vehicles being empty a lot of the time and thus would be very costly. To determine the size and specification of the fleet the MERGE Greenwich consortium considered:

- **Fleet sized for peak demand:** Fleets will be sized in order to meet demand (and service levels) during the peak period. For Greenwich, MERGE Greenwich needed to consider the Monday morning peak as well as peaks at lunchtime and evening. This approach was applied and, after many iterations, the simulations indicated that the utilisation of the fleet remained relatively high throughout the day, up to 74% for the Minibus tier, which indicated the fleet had been sized efficiently.

Ride-sharing services should be designed with allocation and dispatch logic which aims to reach an optimal balance between providing customer convenience, minimising detour time and meeting trip demand

- **Electric or non-electric vehicles:** MERGE Greenwich simulated the AV ride-sharing service with electric vehicles (EVs) in order to minimise emissions from the fleet.

However, the charging requirements for EVs, where the vehicles need to be out of service for a period of time, pose a problem for a business model whereby asset utilisation is key to commercial viability. The power supply requirements will also need to be carefully considered to support such a fleet, as outlined in the report by Driver (2017), regarding EV charging infrastructure requirements²². For these reasons some fleets may choose Plug-in hybrid vehicles (PHEVs), which satisfy the anticipated emission requirements for private hire vehicles in London by 2020. PHEVs come with a typically smaller

22. The provision of rapid charging points in London. Report for Addison Lee by Dr Rebecca Driver, September 2017

range in electric-only mode, compared to battery electric vehicles (BEVs), but can alleviate the logistical hurdle of scheduled charging, as they can use their hybrid engine when the battery capacity drops to a low level.

- **Charging strategy:** As MERGE Greenwich chose to simulate an electric AV fleet it was important to decide how frequently and for how long to charge each vehicle. The aim was to maximise each vehicle's time in operation, minimise the size of the fleet and balance the wear and tear on the battery in order to extend its life as far as possible. MERGE Greenwich decided to take an approach which blends overnight Fast charging (approx. 7 hours at 22 kW) with daytime Rapid charging (1.5 hours at 50kW). This does require an increase in the overall fleet size, in order to compensate for the vehicles which are out of service to recharge during the day. MERGE Greenwich calculated that a 10% increase in the fleet size was required for the Minibus, Standard and Executive tiers of service, in order to allow for ad hoc charging for the most heavily utilised vehicles.
- **Depot strategy:** Deciding how frequently vehicles should return to a depot will be linked to the charging strategy as well as the cleaning and maintenance schedule. For AVs, MERGE Greenwich is suggesting a daily depot visit would be required in order to check the condition of the interior. For this simulation, we have assumed all vehicles return to depot overnight, which also reduces the need for on-street parking. This resulted in a requirement for four depots in Greenwich.
- **Vehicle financing, replacement cycles and residual values:** The cost of the fleet accounts for a third to two-thirds of all running costs, depending on the scale of the service, so finding effective ways to finance the fleet makes a significant difference. MERGE Greenwich discovered that designing a service which achieves

high utilisation of the AV ride-sharing fleet resulted in the vehicles reaching the end of their useful life relatively swiftly. This leads to a short replacement cycle and no residual value, which increases costs when treated as part of a traditional lease arrangement. Innovative financing models, perhaps those which are calculated on a per km basis, could be more effective for this type of service. In addition to this, it must be recognised that the relatively high cost of electric vehicles (mainly due to battery costs) and AVs (mainly due to lidar sensors) is likely to reduce in the coming years but, during the transition period, early adopters are likely to bear the high cost of first generation technology.

- **Vehicle design:** MERGE Greenwich customer research revealed the vehicle design would have an impact on how willing people would be to use an AV ride-sharing service. Large windows, an emergency call button and purpose-built seating were some of the suggestions which indicated bespoke vehicles may be most effective; however, this may increase the base cost of vehicles further still. For the purposes of the MERGE Greenwich blueprint, we have assumed vehicles are similar to those used today and the willingness to use them was directly linked to the customer attitudes expressed during the research.



Electric vehicles are likely to be chosen by mobility fleets in order to reduce emissions, but this has an impact on the cost base as well as changing how the fleet is managed, sized and maintained. Plug-in hybrid vehicles could provide a lower cost alternative, particularly during the transition period.

4.3.3 Operator requirements

In order for customers to want to use an autonomous service, whether for a shared or solo ride, they must have a guarantee of safety and experience a good outcome, both emotionally and tangibly. For today's driven services, even though customers may transact with them digitally, a large component of the customer experience is delivered by the driver.

To deliver the same level of customer experience through a fully autonomous service with no driver on board, MERGE Greenwich concluded some of the driver's role could be delegated to the vehicle (e.g. driving and navigation, authorising who gets into the vehicle, providing a child seat etc.). Other aspects of the driver's role will have to be delegated to kerb-side or venue-based support (e.g. handling bags), digital experience (e.g. trip preferences and information), contact centre support

(dealing with an emergency, assistance or queries) and depot-based support (cleaning, maintenance, repair and charging).

The project also found that, in some cases, the driver role cannot be delegated – for example, the Assist service designed for elderly, infirm, disabled or minor passengers requires a steward on board the vehicle at all times. Similarly, to preserve customer choice, operators could choose to offer a premium service with an on-board 'concierge' to be on hand as and when required, from personal meeting and greeting to carrying luggage.

To make customers want to use an automated service time and time again, the customer experience has to be at the centre of any service design. To achieve full automation, operators must therefore consider not just the operation of the AV technology, but how to deliver a great customer experience when there is very limited or no operator-to-passenger contact during the journey.



To do this well requires an operator model that delivers an experience which is safe and reliable, but which also meets expectations for service and quality and has a degree of personalisation to build a relationship with the customer.

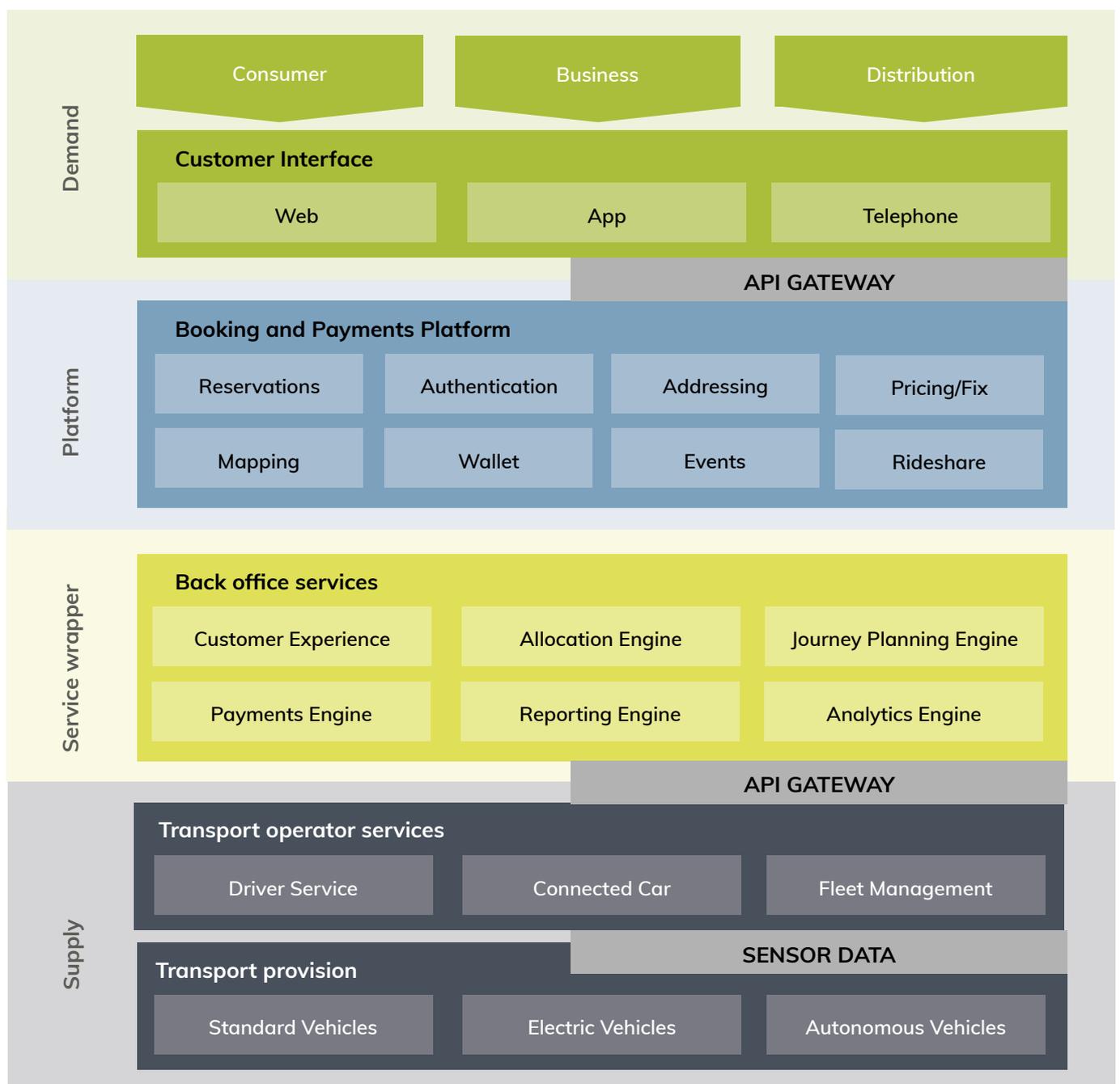
The reference architecture in Figure 6 shows what capabilities an operator must have in order to deliver these services, whether

acting as part of an aggregated Mobility as a Service solution, or offering Mobility as a Service directly.

The capabilities required to deliver an end-to-end service can be summarised as follows:

- The Customer Interface enables the transaction and provides the digital

Figure 6: Reference architecture for a service operator



communications link with the customer. It delivers a range of features which support the service, backed up by customer support in a contact centre. MERGE Greenwich assumed this aspect to be mobile application based, and nearly all communication and transaction with the customer would take place via their personal mobile device. When in the AV, it was assumed the customer could mirror their own applications on screens in the vehicle itself, or have the option to use in-vehicle infotainment systems.

- Connectivity for the customer and to other modes of transport could be delivered through a set of technical interfaces - a managed API (application programming interface) gateway and a library of APIs.
- The booking and payments platform underpins the features provided to the customer and enables the customer to order and pay for their transport services.
- Back Office Services provide the data and rules to govern demand and supply, including what and how the customer can transact, as well as providing a range of services to personalise their experience and provide the full-service support wrapper.
- Transport Operator Services provide capacity and access to vehicles and stewards. Vehicle sensor data is provided to support fleet management and to support allocation and dispatch.
- The operation has to comply with local regulatory requirements, which may include specific rules relating to the use of autonomous vehicles.

Building this capability and gaining the operational experience to guarantee customers have a good outcome from using transport service is vastly expensive, complex and takes considerable time to achieve and get right. Technical implementation is only one part of delivering the service; getting customers to engage with it and use it

time and time again requires development of capability to engage those customers in the service and deliver an end-to-end travel experience that leads to a positive relationship with a customer.

Setting up the service as a stand-alone, new offering with an initially limited scale would therefore mean that it would be very difficult to achieve a positive cash flow in any meaningful time-frame. For this reason, under MERGE Greenwich we decided that autonomous ride-sharing services would be delivered on top of an existing scale operator's capability as a new service benefitting from an economy of scale at a city-wide level, rather than building a new operation and new capabilities from the ground up²³ and seeking to commercialise this in a limited market of one geographic area. This would enable the service to become operational in a relatively short time-frame (by 2025), whilst limiting costs to incremental, rather than high capital expenditure for set-up; and crucially would enable a positive cash flow for the service with certain sensitivities. In addition, quality of service was assumed to be higher due to the scaled capability being established, with customers already engaged in an existing trusted relationship with their provider, making adoption of a new service a smaller step.

4.4 Regulation and policy required

MERGE Greenwich research indicated that regulation and policy decisions will have a significant impact on the design, delivery and demand for an AV ride-sharing service. As a starting point, it will be critical for local authorities to understand their mobility needs and long-term goals, in order to guide mobility providers to design services which meet these needs.

Once the direction has been set by the city, there are several key considerations for implementing an AV ride-sharing service. The MERGE Greenwich report on *City Compatibility: How AV ride-sharing could be implemented*²⁴ explored this area in great

23. A detailed breakdown of operator costs is captured later in this report

Set up costs, the time taken to achieve scale, the time taken to establish a service that customers can trust and achieving profit are significant challenges to new entrants seeking to build and operate AV ride-sharing services. Existing, scale mobility service providers will be better placed to accelerate this new service as a 'bolt on' or evolution to their current business.

detail and concluded the following regulatory and policy elements would need to be considered in order to positively influence the design of AV ride-sharing services:

1. Plan ahead to enable an integrated transport system which uses a common Mobility as a Service platform
2. Focus city planning on designing space for future usage – including reallocating parking space to pick-up and-drop off zones
3. Design AV operations which also accommodate the needs of pedestrians and the street environment
4. Implement smart traffic management on targeted AV ride-sharing corridors
5. Develop tools to assess the suitability of AV routes
6. Scale up investment in charging infrastructure and depot space
7. Develop next generation communications infrastructure to harness the power of connectivity
8. Create a platform for real time data sharing between AV operators and the city which optimises the transport system as a whole
9. Develop regulation to enable next generation mobility services
10. Strengthen public-private collaboration to develop ambitious and integrated

policies which enable the uptake of AV ride-sharing

The combination of service operator and government decisions in the areas listed above will determine how the AV ride-sharing service operates, how customers experience the new mode of transport and, ultimately, the impact on the transport network in the city.

In order to build on these findings, MERGE Greenwich designed three AV ride-sharing service blueprints, which were built into the transport model and fleet simulation. Each blueprint was designed with a different purpose in mind: one aimed to offer a mass-transit solution at low cost, the second aimed for a greater level of customer convenience but at a higher price and the third aimed to build on the findings from the first two in order to develop a blueprint which combined the best of both worlds.

This approach enabled an assessment of how different fare and service level parameters would impact the uptake of AV ride-sharing. To improve the robustness of the analysis, over a thousand model iterations were run to test the service specifications and ensure they could be refined before the three blueprints described in this report were finalised. Results from the model and simulation were combined with the business model in order to assess the societal impact and commercial viability of each blueprint, the results of which will be explored later in this report.

5. AV ride-sharing service blueprints

5.1 Baseline assumptions for all blueprints

For the purposes of this project we assumed certain aspects remained the same across all blueprints. These include:

- All blueprints are based on the year 2025 and assume that AVs are readily available for fleet operation as well as there being a high acceptance of ride-sharing among passengers.
 - Payment for AV ride-sharing trips will be integrated with public transport systems in order for passengers to use all modes of transport seamlessly.
 - Pick-up and drop-off locations will be chosen by the customer – i.e. there are no predefined pick-up or drop-off points which the customer has to walk to/from.
 - The route is flexible and optimised for the journey – i.e. this is not a fixed route shuttle service.
 - Four charging depots will be in place, distributed across the chosen location, so that all vehicles can recharge overnight.
 - A steward will be on board all vehicles where passengers express the need for assistance (the Assist tier of service).
- MERGE Greenwich research indicated that 7% of all trips in the Borough require assistance, hence the emphasis placed on including this service option across all blueprints.
- Price points were set to be consistent with similar services which exist today and were cross-checked against research such as the GATEway project²⁵. GATEway research found people were willing to pay an average fare of £2.06 for an AV pod, which is closer to a tube fare (£2.40) than a bus fare (£1.50).
 - All fares were on a per-trip basis and no dynamic of ‘surge’ pricing was applied.
 - The time value of money was considered for all modes of transport.
 - The ambition of all services is to encourage private car users to switch to AV ride-sharing but not to entice passengers away from public transport or sustainable modes, such as walking and cycling.

For each of the blueprints to achieve different objectives, price points and service levels were set for each tier of service based on the maximum waiting time, detour times and trip fulfilment. These values were the parameters or ‘levers’ used as inputs to the demand and fleet modelling.



5.2 The accessibility blueprint

The accessibility blueprint aims to offer a readily accessible and affordable on-demand

AV ride-sharing service, which is available to all citizens and maximises passenger transport accessibility in the city.

Figure 7: The accessibility blueprint



This blueprint was designed to offer a low cost, highly accessible, mass-market service. The aim of this blueprint was to test the impact of AV ride-sharing if it was delivered as a public service.

In this blueprint, mass-transit services are offered (Minibus tier) along with the option to request assistance from an on-board steward (Assist tier), in order to meet the needs of the majority of the population.

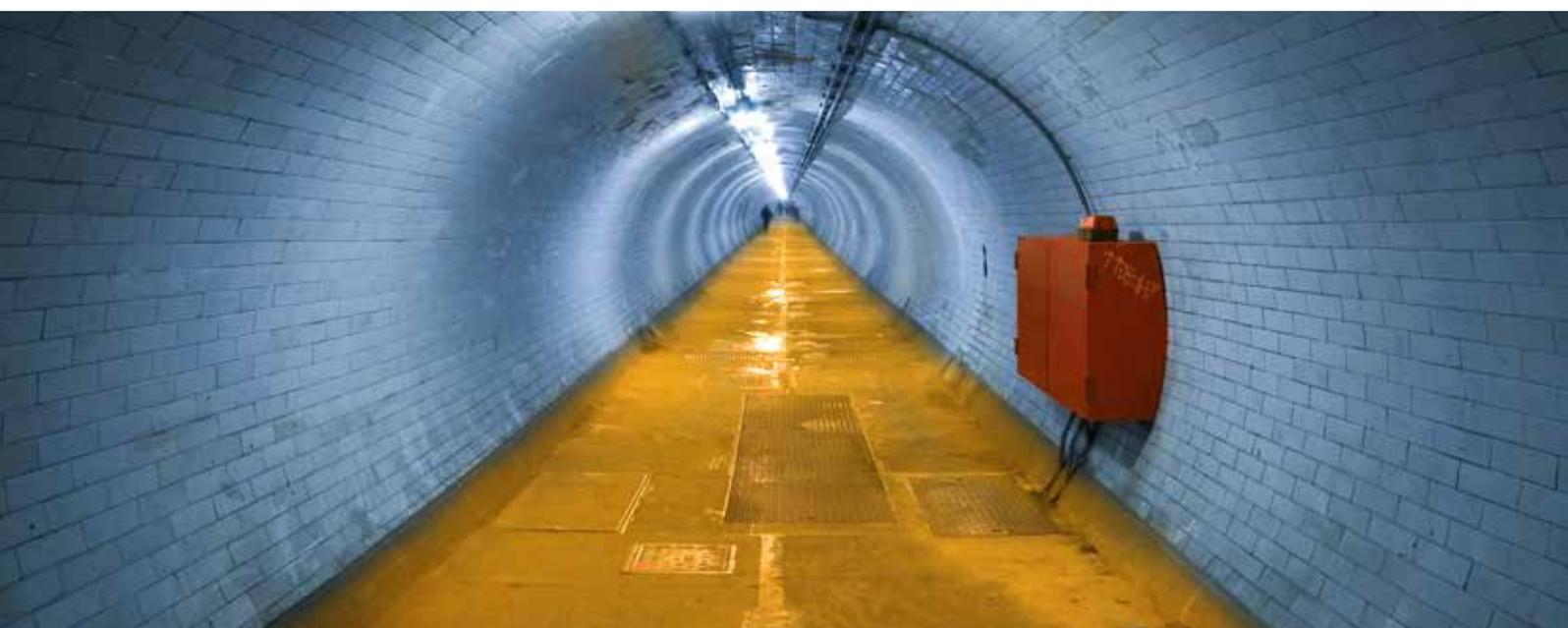
A low-cost flat fare of £2.60 was applied to all trips, which was chosen to be comparable

with existing public transport fares, yet not so low as to compete directly with buses (current bus fares are £1.50 in Greenwich). The level of service, defined in terms of maximum waiting time, maximum detour distances during trips and the level of trip fulfilment, is intended to encourage a high level of sharing and minimise the number of vehicles needed. As this blueprint does not prioritise customer convenience, slightly longer waiting times may be experienced, along with a high level of sharing. Solo rides cannot be requested in this blueprint.

In order to be comparable with public transport today, the service fulfilment level for this blueprint was set at 80% (90% if passengers requested assistance). This means that at peak times, the fleet must

be large enough to cater for at least 80% (or 90% with assistance) of trips requested. If trips cannot be fulfilled by the AV ride-sharing service the passenger is redirected to their usual mode of transport.

The accessibility blueprint		
Tiers offered	Minibus	Assist
Flat fare	£2.60	£2.60
Average waiting time	4.3 mins	0.6 mins
(Maximum waiting time)	(25 mins)	(10 mins)
Average detour time experienced	4.8 mins	10.3 mins
(Maximum detour ratio ²⁶)	(500%)	(150%)
Target trips fulfilled by AV ride-sharing ²⁷	80%	90%



26. This refers to the additional time a trip could take due to picking up/dropping off other passengers. For example, a typical 10-minute journey with a 100% detour ratio could take up to 20 minutes.
 27. This means the AV fleet must be large enough to cater for this proportion of trips, by meeting all service level targets, at peak times. If a trip cannot be fulfilled by the AV service, the passenger uses their current mode.

5.3 The convenience blueprint

The convenience blueprint takes a ‘free market’ approach and aims to deliver an AV ride-sharing service which prioritises customer convenience and provides a greater level of service.

Figure 8: The convenience blueprint



Increased customer convenience is achieved by designing the service with lower waiting and detour times, but at a higher price. This blueprint is designed with smaller vehicles (Standard and Executive tier), which cannot be considered mass transit and could be requested for a solo trip (Executive tier). The option to request assistance (Assist tier at a flat fare of £2.60) is still available, as in the accessibility blueprint.

This blueprint assumes the service is operated by a private sector provider, which implies the provider will not benefit from public subsidies

but may require alternative private funding solutions. The aim of this service design is to achieve all operator-related KPIs e.g. optimal profit, increased service utilisation and optimal customer experience.

In this blueprint, a minimum fare is applied (between £5 and £6.50) which would be expected to discourage passengers from switching away from current modes of public transport. Beyond this minimum fare, a price per km is charged, which aims to make the service commercially viable.

The convenience blueprint

Tiers offered	Assist	Standard	Executive
Flat fare	£2.60	-	-
Minimum fare	-	£5.00	£6.50
Price per km (charged once the minimum fare has been exceeded)	-	£0.96/km	£2.80/km
Average waiting time (Maximum waiting time)	0.7 mins (10 mins)	2.2 mins (15 mins)	0.3 mins (10mins)
Average detour time experienced (Maximum detour ratio)	10.45 mins (500%)	2.9 mins (300%)	1.0 mins (50%)
Target trips fulfilled	90%	90%	95%

The average waiting time on the Executive tier is particularly low (18 seconds) because, in most cases, these vehicles are waiting at the pick-up spot ahead of the pick-up time. This is due to the simulation being able

to predict trip demand in order to allocate and pre-position vehicles and illustrates how predictive positioning can support particularly high service levels.

5.4 The combined blueprint

The design for the combined blueprint was based on learnings from testing and analysing the accessibility and convenience blueprints. With this blueprint, MERGE Greenwich aims to balance accessibility and convenience, in order to deliver an AV ride-sharing service which meets the needs of the

city, consumers and operators. If delivered in this way, the MERGE Greenwich consortium aims to illustrate that AV ride-sharing could be integrated with public transport in a way which helps enhance mobility, increases customer choice and delivers the wider benefits which autonomous and electric vehicle technology provide, whilst being a cost-effective use of public funding.

Figure 9: The combined blueprint



In this blueprint a wide range of services are offered; for example mass transit, solo trips and on-board assistance can be requested. The expectation is that mass transit and assisted services would be operated by a public entity, while private operators would offer more convenient services through the Standard and Executive tiers. The flat fare for the Minibus tier was increased to £3.50 in this blueprint (compared to £2.60 in the accessibility blueprint) in order to reduce switching from public transport to AV ride-

sharing. All other pricing and service levels remained the same.

The combined blueprint

As in the convenience blueprint, the Executive vehicles are frequently pre-positioned in order to minimise waiting time (average 13 seconds) and maintain the highest level of service. We can also see that service fulfilment levels are reaching their targets, which means the fleet for each tier of service has been appropriately sized.

The combined blueprint

Tiers offered	Minibus	Assist	Standard	Executive
Flat fare	£3.50	£2.60	-	-
Minimum fare	-	-	£5	£6.50
Price per km (charged once the minimum fare has been exceeded)	-	-	£1.14/km	£2.8/km
Average waiting time (Maximum waiting time)	5.3 mins (25 mins)	0.8 mins (10 mins)	2.4 mins (15 mins)	0.2 mins (10 mins)
Average detour time experienced (Maximum detour ratio ²⁸)	5.7 mins (500%)	10.2 mins (150%)	3.0 mins (300%)	1.0 mins (50%)
Target trips fulfilled ²⁹	80%	90%	90%	95%

AV ride-sharing services can be designed to achieve city objectives, meet customer needs and fulfil operator requirements. How these aspirations are balanced can have very different outcomes.

28. This refers to the additional time a trip could take due to picking up/dropping off other passengers. For example, a 10-minute journey with a 100% detour ratio could take up to 20 minutes.
29. This means the fleet must be large enough to cater for this proportion of trips, by meeting all service level targets, at peak times.

6. Results and impacts of blueprint design

Following a detailed simulation of each blueprint, MERGE Greenwich was able to compare and contrast the impact of different service designs on the city, passengers and operators. The headline findings from each blueprint are:

- The accessibility blueprint is by far the largest scale service, with 706 vehicles in the fleet completing over 31,500 passenger trips per day in Greenwich. This blueprint aimed to deliver a low cost, mass transit service with relatively low service levels and it is clear from the modelling and simulation results that this outcome has been achieved. This blueprint indicated it could cater for over a quarter (28%) of all trips in Greenwich on a given day, achieving a high level of sharing and the lowest level of empty running.
- The convenience blueprint, which aimed to deliver a higher level of service at a higher price, experienced a fraction of the demand compared to the accessibility

blueprint. Completing just over 9,000 passenger trips per day, which represents 8% of the total daily trips in Greenwich, this service required a fleet of just 332 vehicles. Compared to the accessibility blueprint, this means the convenience blueprint completed a third of the trips but still required half the number of vehicles in order to achieve target service levels. This led to a relatively high level of empty running, particularly in the Executive tier.

- The combined blueprint aimed to be ‘the best of both worlds’ by offering all four tiers of service at a range of price points and service levels. The result of this was demand of over 17,500 passenger trips per day, equivalent to 16% of all trips made in Greenwich daily, which could be achieved with a fleet of 458 vehicles.

The table opposite illustrates the different size and scale of each service, according to the different blueprint designs.



Overview of blueprint results	The accessibility blueprint	The convenience blueprint	The combined blueprint
Total AV ride-sharing fleet size (number of vehicles)	706	332	458
Trips served per day	31,536	9,264	17,512
% of theoretically sharable trips served	28%	8%	16%
Mean waiting time mins:secs	4:21 (Minibus) 0:37 (Assist)	0:15 (Executive) 2:10 (Standard) 0:39 (Assist)	0:12 (Executive) 5:15 (Minibus) 2:24 (Standard) 0:47 (Assist)
Mean detour time	4:46 (Minibus) 10:16 (Assist)	0:59 (Executive) 3:14 (Standard) 10:27 (Assist)	0:59 (Executive) 5:41 (Minibus) 2:59 (Standard) 10:09 (Assist)
% of trips fulfilled	80% (Minibus) 91% (Assist)	93.5% (Executive) 90.9% (Standard) 91.2% (Assist)	98.6% (Executive) 84.7% (Minibus) 89.2% (Standard) 92.3 (Assist)
Total kms of the AV fleet per day	254,241	98,200	159,752
% 'empty running' kms per AV	20%	51%	32%
Vehicle occupancy (average number of people in the vehicle at peak times)	2.5 (Minibus) 1 (Assist)	1 (Executive) 2 (Standard) 1 (Assist)	0.4 (Executive) 2.5 (Minibus) 1.5 (Standard) 1 (Assist)

Designing an AV ride-sharing service which prioritises accessibility will produce the largest scale service with the highest degree of shared trips, but this may have an adverse impact on congestion by taking passengers who would otherwise travel by bus, walk or cycle.

6.1 Modal shift caused by the introduction of AV ride-sharing

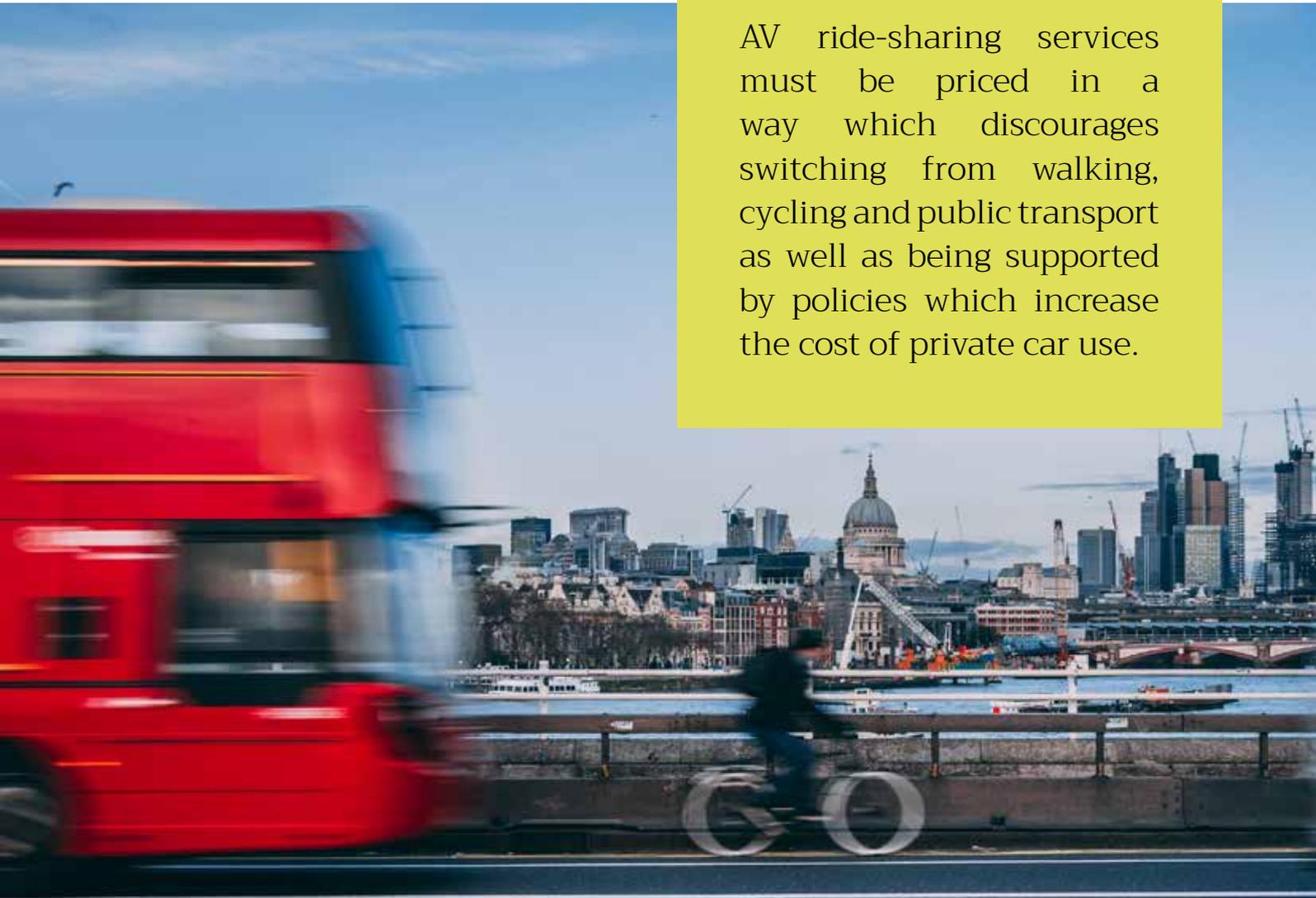
MERGE Greenwich assessed the level of modal shift, particularly from private cars and buses, which could occur if AV ride-sharing was introduced. The ambition was to design a service which encourages private car users to switch to AV ride-sharing but not to compete with existing public transport services. The following section indicates how realistic this ambition might be.

6.1.1 Modal shift from public transport and private cars

A higher proportion of passengers switch from buses than from private cars as a result of the AV ride-sharing service offering greater convenience and reduced travel times at a relatively low cost. The accessibility blueprint achieved the greatest uptake for AV ride-sharing but attracted 34% of passengers from buses compared to 14% from private cars. The table below indicates the proportion of car and bus users who switch to AV ride-sharing under each blueprint.

		Base case (excluding AV ride-sharing)	The accessibility blueprint	The convenience blueprint	The combined blueprint
Total daily trips made by each mode	Cars (driven)	71,456	60,916	67,220	65,572
	Car (passengers)	14,268	12,952	13,736	13,660
	Public transport (bus)	57,584	37,904	53,088	46,564
	AV ride-sharing	-	31,536	9,264	17,512
	Total trips all modes ³⁰ :	143,308	143,308	143,308	143,308
Modal shift to AV ride- sharing (% trips switched from each mode)	Cars (driven)	-	15%	6%	8%
	Car (passengers)	-	9%	4%	4%
	Cars (driven and passengers)	-	14%	6%	7%
	Public transport (bus)	-	34%	8%	19%

30. The MERGE Greenwich transport model assumed demand would remain constant when AV ride-sharing was introduced. Further research is required to understand whether this new service could lead to more people (e.g. elderly/disabled) choosing to travel if on-demand AV modes were available.



AV ride-sharing services must be priced in a way which discourages switching from walking, cycling and public transport as well as being supported by policies which increase the cost of private car use.

MERGE Greenwich tested the impact of a price increase on mobility shift from public transport by increasing the price for the minibus from £2.60 (accessibility blueprint) to £3.50 (combined blueprint). This reduced switching from buses from 34% to 19%. Similarly, when the entry price is raised to £5 (minimum fare for the Standard tier in the convenience blueprint), switching from buses fell to just 8%.

However, it is important to note that competition with bus services is not always an unsustainable outcome. Where populations are sparse and journeys are widely distributed, for example in rural areas, it is very expensive to provide bus services, and those that are provided often have low

occupancy levels. In these locations AV ride-sharing could provide a more cost-effective alternative that does not cause an overall increase in road traffic.

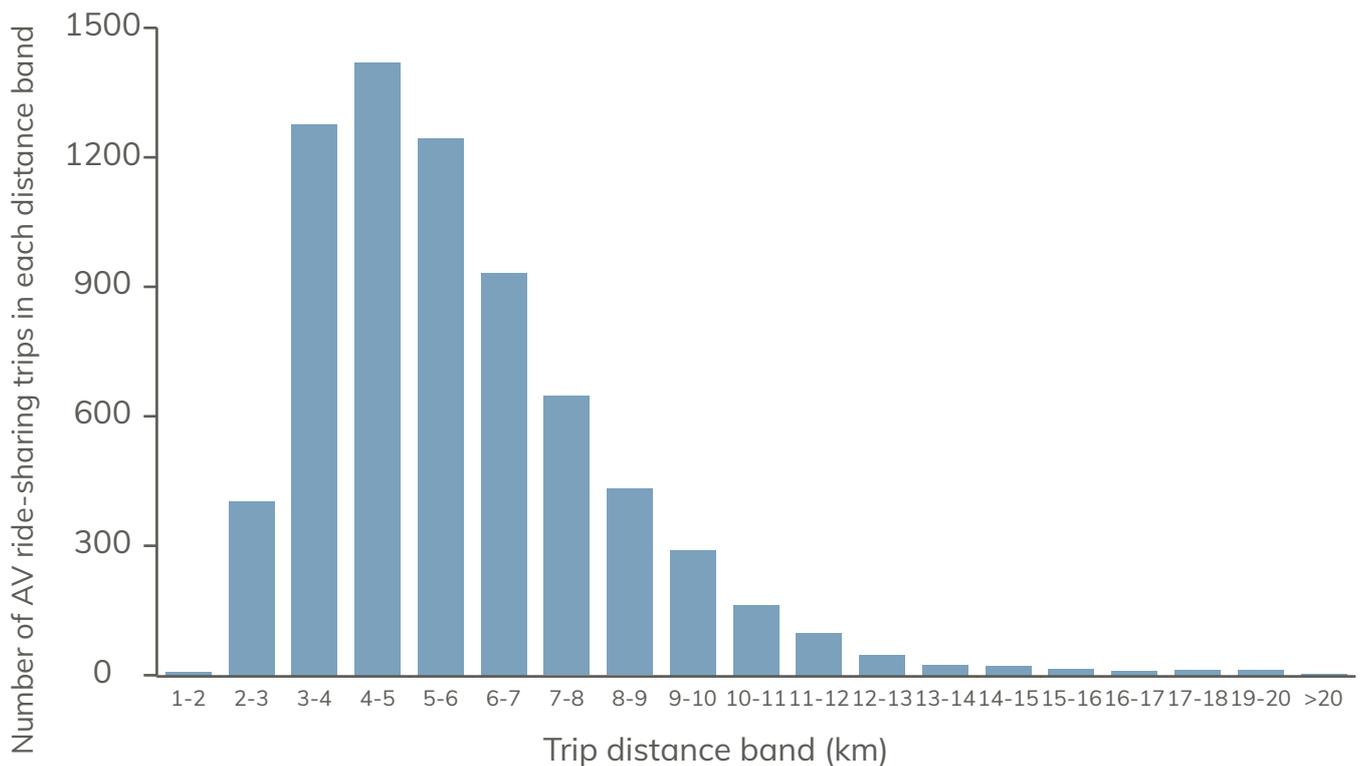
To increase switching from car users, AV ride-sharing services will need to remain comparable to car costs. However, parking and other motoring costs have a greater impact on modal switch from this group, as discussed in *Pricing as a determinant of demand* (section 4.1.6). This reinforces the need for AV ride-sharing services to be designed in a way which appeals to private car users more than public transport users and may need to be supported by external policies and pricing structures which reinforce this behaviour pattern.

6.1.2 Modal shift from walking and cycling

MERGE Greenwich tested whether the introduction of AV ride-sharing would

cause people to give up sustainable modes of transport, such as walking and cycling. Figure 10 shows the typical distribution of AV ride-sharing trip distances.

Figure 10: In all blueprints, half of the AV ride-sharing trips were within walking or cycling distance



In all blueprints most trips were between 4 and 5kms. This is a relatively short distance that would also be considered to be within cycling range (89% of current cycle trips in London are below 5km; TfL analysis has concluded that 23% of all trips made by mechanised modes are 'potentially cyclable'³¹). Although cycling was not included in the model, these results suggest that there is a risk of AV ride-sharing abstracting from cycling and walking.

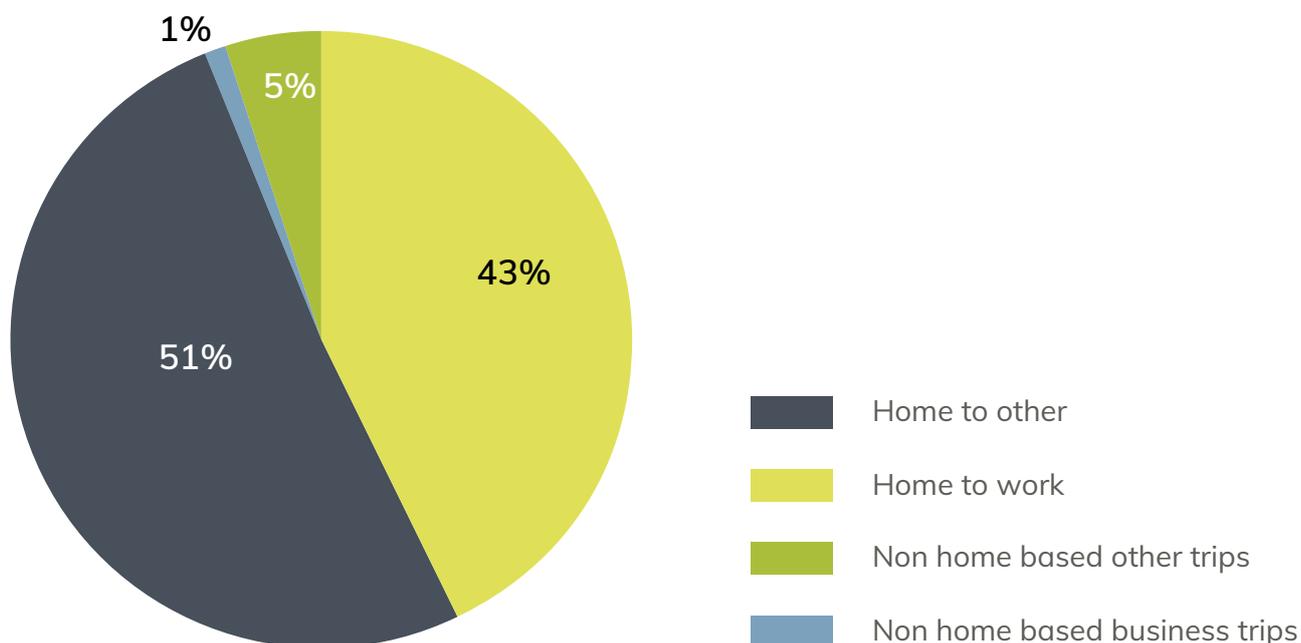
To minimise these instances, MERGE Greenwich suggests a minimum fare is maintained and softer measures, such as gamification in the booking app, are used

to influence behaviour and encourage passengers to benefit from sustainable modes where possible. This would need to be supported by complementary measures which continue to encourage walking and cycling.

In all blueprints, half of the AV ride-sharing trips were within walking or cycling distance.

31. Analysis of cycling potential, taking account of the nature of journeys made and people's ability to cycle, Transport for London, 2010

Figure 11: The majority of trips using AV ride-sharing began from or ended at home



MERGE Greenwich also looked into the types of journeys for which AV ride-sharing might be used. The research found that people may be more willing to use AV ride-sharing for some types of journey than for others, as shown by the four journey types in Figure 11. The highest share of AV ride-sharing trips,

48%, is for travel from home to work and for people travelling in the course of work. The lowest share (37%) was for travel from home on personal business. These results help to identify which groups should be targeted when AV ride-sharing services are introduced.

The majority of trips using AV ride-sharing began from or ended at home

6.2 Mobility gaps and other benefits to users

The MERGE Greenwich report on City Compatibility: How AV ride-sharing can address mobility gaps³² outlined how this new service could improve transport within

our cities. Through the simulation we were able to investigate how these mobility gaps could be addressed, by reducing journey times, providing accessible transport in poorly connected areas and reducing travel costs.

32. <https://mergegreenwich.com/city-compatibility-how-av-ride-sharing-could-address-mobility-gaps>

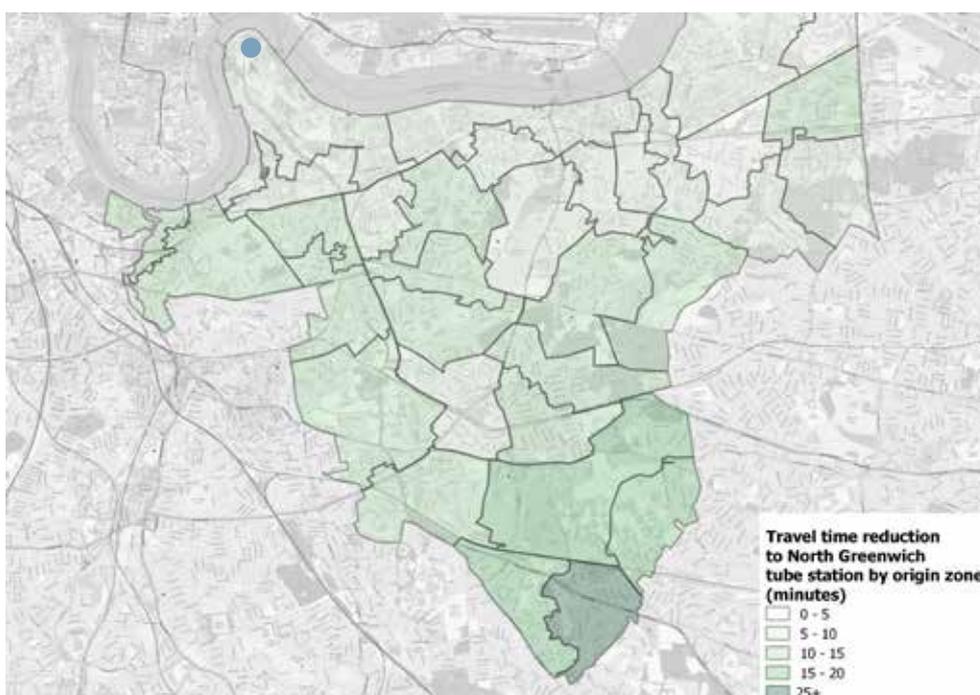
6.2.1 Reducing journey time to transport hubs

We can see from the table below that the average journey time to a key transport hub, North Greenwich tube station in this example, is significantly reduced by AV ride-

sharing compared to public transport. The accessibility and convenience blueprints show a time saving of 43% (about 13 minutes for a journey which would take 22 minutes by public transport). This is the equivalent of a regular commuter saving 3.5 days per year in travel time³³.

		Base case (excluding AV ride-sharing)	The accessibility blueprint	The convenience blueprint	The combined blueprint
Average journey time (minutes) to North Greenwich tube station from poorly connected areas	By public transport (bus)	22.5	23.2	22.6	22.2
	By car	11.1	11.1	11.5	10.9
	By AV ride-sharing	-	13.3	12.9	17.4
% reduction in journey time to North Greenwich	Compared to public transport	-	43%	43%	21%

Figure 12: AV ride-sharing could reduce the journey time to transport hubs



33. Based on making this journey twice a day, 260 working days per year

AV ride-sharing could be an effective ‘feeder’ for public transport by reducing travel time to hubs such as North Greenwich tube station.

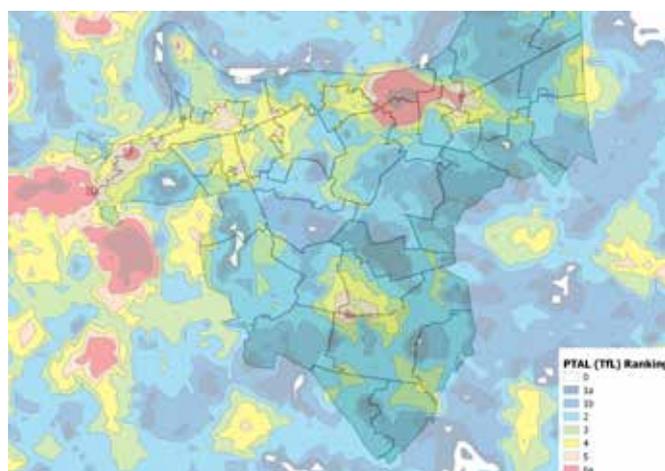
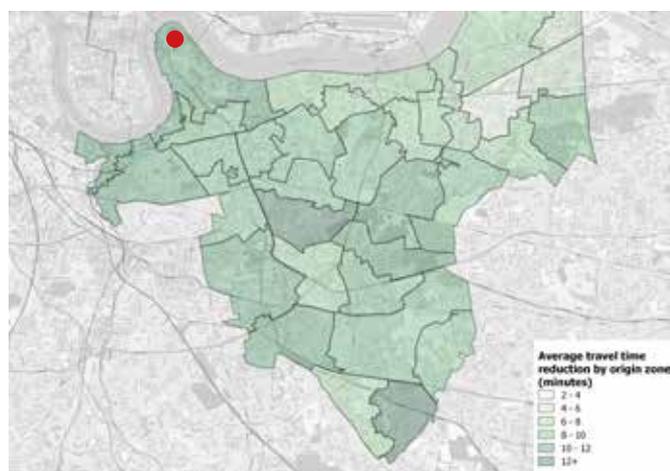
6.2.2 Linking poorly connected areas

In addition to providing an effective ‘feeder’ service for public transport hubs AV, ride-sharing could address mobility gaps by reducing journey times in neighbourhoods which are currently underserved by public transport.

Figure 13, below, shows the correlation between significantly reduced journey times and the areas which currently have a low

public transport accessibility level (PTAL) rating. MERGE Greenwich analysis showed that if AV ride-sharing is designed to address this mobility gap directly (the accessibility blueprint) an average journey time reduction of 53% can be achieved, compared to public transport (saving 8 minutes). When the service is designed for maximum convenience, albeit at a higher price (the convenience blueprint), journey times can be reduced by 74% (saving 10 minutes).

Figure 13: AV ride-sharing could address mobility gaps by reducing travel time from poorly connected areas



● North Greenwich tube station

These examples illustrate how AV ride-sharing could address mobility gaps and reduce overall journey times, particularly in poorly connected areas.

The convenience blueprint reduced journey times the most; up to 74% in poorly connected areas.

6.2.3 Reducing the cost of travel

It is helpful to compare how the benefits of using AV ride-sharing compare between bus users and car users. In summary, bus users benefit from reduced journey times while car users benefit from a lower cost per trip. The latter is particularly influenced by parking costs, which is one of the main drivers of modal shift in the demand model.

To compare the overall benefit the 'generalised cost' can be calculated and compared. This combines direct costs, such as fares, fuel costs and parking charges, with the value of time spent travelling and waiting. Figure 14 compares the generalised cost per trip for AV ride-sharing users that have switched from buses with those that have switched from cars. This analysis shows that car users receive a larger overall benefit from using AV ride-sharing than bus users do, as they gain significantly larger generalised cost savings.

This suggests that car users could, in principle, pay higher fares while still benefiting from switching to AV ride-sharing; while bus users would be less likely to do so. This would have the benefit of improving the commercial viability of the service, while discouraging bus users to switch mode. Measures to discourage private car use, such as increased parking charges and road pricing, would further increase the benefit of using AV ride-sharing instead of driving.

Conversely, as the main benefit of using AV ride-sharing services is saving time, then measures to improve bus journey times (such as shorter waiting times), would reduce the attractiveness of AV ride-sharing. A package of complementary transport policy measures that increase the cost of private driving while improving the quality of bus services would therefore encourage modal shift to AV ride-sharing from private cars while minimising abstraction from public transport.

Figure 14: Switching to AV ride-sharing provides greater generalised costs savings³⁴ for car users than bus users.



34. Generalised costs combine direct costs, such as fares, fuel costs and parking charges, with the value of time spent travelling and waiting

6.3 Impact on traffic and parking

The MERGE Greenwich simulation calculated the distance travelled for each trip, by each mode, and the total distance travelled by the AV ride-sharing fleet. Clearly, if people who were previously travelling separately in cars transferred to AV ride-sharing and shared a journey, the total distance driven would be very likely to fall. On the other hand, where bus passengers shift to AV ride-sharing then, even if they share a journey, the total distance driven will increase. In addition, there is inevitably some empty running in the AV ride-sharing fleet as vehicles re-position themselves between trips.

6.3.1 Increase in total kms driven

As explained previously, the simulated blueprints showed a shift to AV ride-sharing from both private car and bus. Whilst this causes an overall reduction in the number of vehicles on the road and does not adversely affect journey times by either car or bus, the addition of a new fleet does result in an increase in overall kms.

The table below shows that although the total distance driven by private cars drops by over 53,000kms under the accessibility blueprint, there is a larger increase in AV ride-sharing kms, which leads to an overall increase in vehicle kms of approximately 57%. This increase in total vehicle kms can be offset to a degree, by avoiding the additional distance that private drivers undertake in order to find a car parking space, which can be 5% to 10% in urban centres.

		Base case (excluding AV ride-sharing)	The accessibility blueprint	The convenience blueprint	The combined blueprint
Total kms completed by	Car	329,077	275,793	309,596	298,850
	AV ride-sharing	-	239,715	86,534	151,335
Change in kms	Change in private car kms	-	-53,284	-19,481	-30,227
	Overall change in total vehicle kms (car + AV ride-sharing)	-	186,431	67,053	121,109
	% increase in total kms	-	57%	20%	37%



AV ride-sharing could increase the total kms if it abstracts significant numbers of users from buses. Similarly, this could impact total emissions unless the majority of AV ride-sharing customers come from private car users.

6.3.2 Increase in occupancy

In terms of vehicle occupancy, AV ride-sharing vehicles are being used more efficiently than private cars, with an average occupancy in

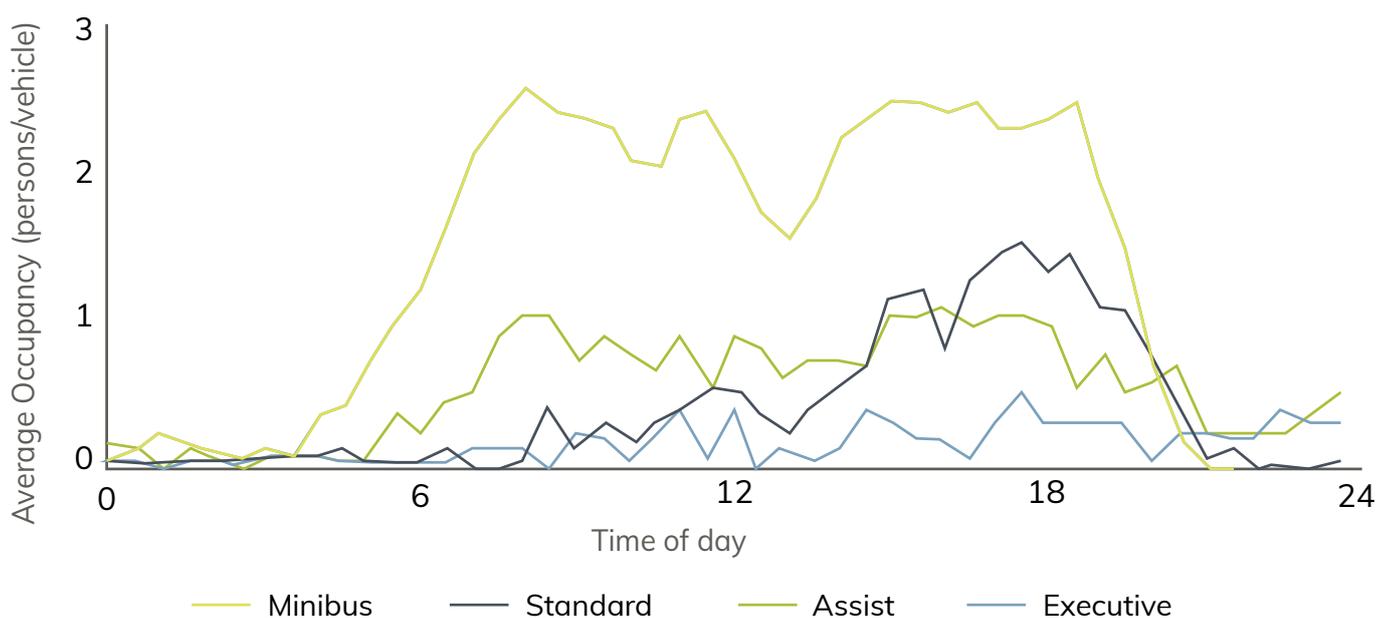
the Minibus tier of 2.5 passengers per vehicle in the commuting peak, compared with an average of 1.2 per vehicle for commuting trips by private cars.

Vehicle occupancy	The accessibility blueprint	The convenience blueprint	The combined blueprint
AV ride-sharing occupancy at peak times	2.5 (Minibus) 1 (Assist)	1 (Assist) 2 (Standard) 1 (Executive)	2.5 (Minibus) 1 (Assist) 1.5 (Standard) 1 (Executive)

Occupancy varies throughout the day and for different tiers of service, as shown in Figure 15³⁵. The Minibus and Assist tiers experience relatively consistent demand throughout the day as they attract a balance of commuters and leisure passengers. However, the higher priced Standard and Executive tiers are

predominantly used by business travellers and therefore experience more demand during the evening peak. Occupancy of the AV ride-sharing fleet could be improved by offering a broader range of trips (e.g. outside the Borough), reducing the size of the fleet and/or relaxing the target service levels.

Figure 15: Average occupancy of AV ride-sharing vehicles is more consistent throughout the day for the Minibus and Assist tiers than for Standard and Executive tiers



Simulation indicated the average occupancy of AV ride-sharing vehicles could be double that of private cars during peak times (2.5 passengers per AV Minibus, compared to 1.2 passengers per private car).

6.3.3 Reduced need for parking spaces

One significant benefit that arises from these services is that there is a large reduction in demand for parking spaces at the destination³⁶. The AV ride-sharing simulation showed that parking is no longer required for up to 38% of all trips made in a day (accessibility blueprint). The reduction in

demand for parking spaces is even greater, 45%, for trips made by commuters who are likely to need the parking space for the whole working day. In the accessibility and combined blueprints, this meant around 1,600 parking spaces could be freed up in the Borough. This is the equivalent of approximately 4 acres in Greenwich, or 61 tennis courts, which could be used in other ways.

³⁵. These figures represent average occupancy of vehicles within a particular tier of service.

³⁶. MERGE Greenwich assumes an out of town depot will be in place for vehicles to park, charge and be serviced overnight, thus no need to provision for on-street parking for the AV fleet

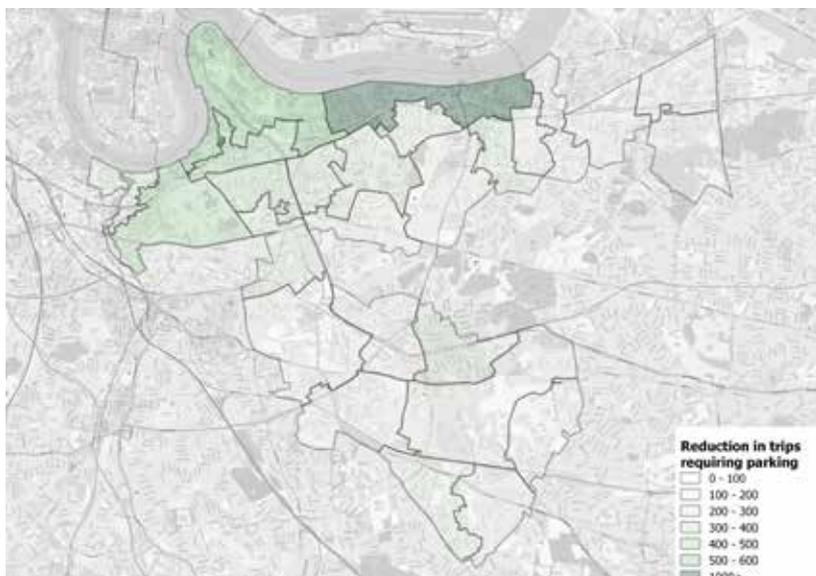
Demand for trips which require parking

	The accessibility blueprint	The convenience blueprint	The combined blueprint
Total trips which no longer require parking	4,900	2,140	3,216
% total trips which no longer require parking	38%	16%	25%
Commuter trips which no longer require parking	1,632	1,348	1,672
% commuter trips which no longer require parking	45%	38%	47%

This has a lot of consequential benefits for cities, such as reducing congestion and obstruction and freeing up road space for more beneficial purposes, although there may be parking revenue implications for local authorities. The map in Figure 16 illustrates where in Greenwich these parking spaces

would most likely be freed up. It is important to note, however, that if parking spaces are simply freed up and not reallocated to a different purpose then this could have the effect of encouraging further demand for bringing private cars into the city, i.e. releasing suppressed demand.

Figure 16: Estimated reduction in the number of trips requiring a parking space



AV ride-sharing could reduce the number of trips which require parking by up to 38%. In Greenwich, this means up to 61 tennis courts' worth of valuable urban space could be reallocated for other uses.

It will therefore be necessary to ensure that AV ride-sharing services are designed to minimise empty running and maximise ride-sharing in order to reduce any negative impacts on traffic while maintaining a positive impact on the reduced need for parking space. This might involve:

- Higher prices in comparison with bus fares, but maintaining fares which are lower than private car parking costs, congestion charges, etc.
- Increasing the allowed waiting times and detour distance to increase ride-sharing
- Further improvement to the vehicle allocation algorithm to reduce empty running
- Designing AV ride-sharing routes and pick-up and drop-off locations to ensure that AV ride-sharing networks are complementary to, rather than competing with, bus routes

6.4 Environmental and safety impact of AV ride-sharing

As MERGE Greenwich aimed to understand whether AV ride-sharing could contribute towards the MaaS vision of making cities greener, more efficient and more accessible, we assessed the potential environmental and safety impacts of introducing this new mode of transport.

6.4.1 Tailpipe emissions reduce, but reducing CO₂ depends on renewable electricity

MERGE Greenwich assumed the AV fleet would be electric in order to reduce emissions and improve air quality as far as possible. The simulated blueprints indicated a reduction in private car usage could occur if AV ride-sharing was introduced. This means local, or tailpipe, emissions (NO_x and PM) would reduce each time AV ride-sharing was used instead of a private internal combustion engine vehicle.

However, despite a reduction in the overall fleet size, the electric AVs were carrying passengers who previously took the bus, leading to a net increase in total kms of 20% - 57%, depending on the blueprint. This increase in overall kms may lead to an increase in CO₂ emissions unless renewable energy sources are used to charge the fleet. The blueprints modelled by MERGE Greenwich indicated this led to an increase in CO₂ of 24% for the largest scale service (accessibility blueprint)³⁷.

This impact can be reduced by:

- Charging the AV fleet from renewable sources (solar, wind or nuclear). If the modelled blueprints were assumed to be charged in this way there would be an overall reduction in CO₂ emissions of 16% because of the reduction in kms from private cars. (On the other hand, if the private car fleet becomes electrified the impact of switching to AV ride-sharing would be less significant).
- Ensuring sufficient numbers of car passengers switch to AV ride-sharing in order to reduce the overall kms and therefore lead to a net reduction in emissions.
- Improvements in EV and AV technology, which would lead to lower energy per km consumed by electric vehicles in the future and lower power required by the AV sensors and computing hardware respectively.

While improved vehicle efficiency and increased use of renewable energy could enable a reduction in CO₂ emissions, the priority is to ensure that AV ride-sharing is introduced alongside a package of measures which encourage greater uptake from private car users than bus users. If this is achieved then significant CO₂ savings would be possible even with the current vehicle efficiencies and power generation mix.

37. Based on the forecast energy mix in 2025 and estimates of 0.128Kg CO₂ per km for average cars by 2025, using the Defra Emissions Forecasting Tool"

Emissions	Base case (excluding AV ride-sharing)	The accessibility blueprint	The convenience blueprint	The combined blueprint
AV power consumption kWh/km	-	0.34	0.251	0.324
AV emissions factor CO ₂ /km	-	0.071	0.052	0.067
Car emissions kg CO ₂	42,122	35,302	39,628	38,253
AV emissions kg CO ₂	-	16,921	4,509	10,180
Total emissions kg CO ₂	42,122	52,222	44,138	48,432
Change in emissions kg CO ₂	-	+10,100	+2,016	+6,311
% increase on baseline CO ₂ emissions	-	+24%	+5%	+15%
Change in emissions from private cars kg CO ₂		-6,820	-2,494	-3,869
% decrease in emissions from cars		-16%	-6%	-9%

6.4.2 Impact on collisions

In order for self-driving technology to become mainstream and widely accepted it has to be proven to be much safer than human drivers. The new technology is likely to be held to a higher account by regulators, policy and law makers and insurers, as well as by the vehicle manufacturers themselves who may use safety as a point of differentiation. The MERGE Greenwich project assumed this will have been achieved by 2025 and simulated the AV ride-sharing service is if it was available to the public.

The safety implications of AVs during the transition period are uncertain. Whilst it is widely acknowledged that over 90% of road accidents involve human error, there is not enough evidence to allow meaningful conclusions to be drawn from the simulations on the safety of the interaction between AVs and human road users. Total vehicle kms do increase under the MERGE Greenwich simulations as the modelled AV traffic is greater than the reduction in private car traffic, but it is unclear if the probability of accidents would increase as a result. Using

tools developed by MERGE Greenwich, future AV ride-sharing services should aim to maximise the potential safety benefits of AV by designing AV ride-sharing services that attract passengers primarily from private

cars and thereby reduce overall traffic levels.

Further considerations regarding the implementation of AVs were captured in the MERGE Greenwich report *City Compatibility: How AV ride-sharing could be implemented*³⁸.

AV ride-sharing fleets which are electric can reduce local (tailpipe) emissions and improve air quality. When combined with vehicle charging from a renewable supply, AV ride-sharing fleets could help to achieve national CO₂ policy objectives.



38. www.mergegreenwich.com/city-compatibility-how-av-ride-sharing-could-be-implemented



Whilst it is commonly assumed AV technology will be safer than human drivers, it is too early to quantify any benefits on this basis and further thought will be required to ensure the new technology is introduced appropriately

6.5 Commercial viability of AV ride-sharing

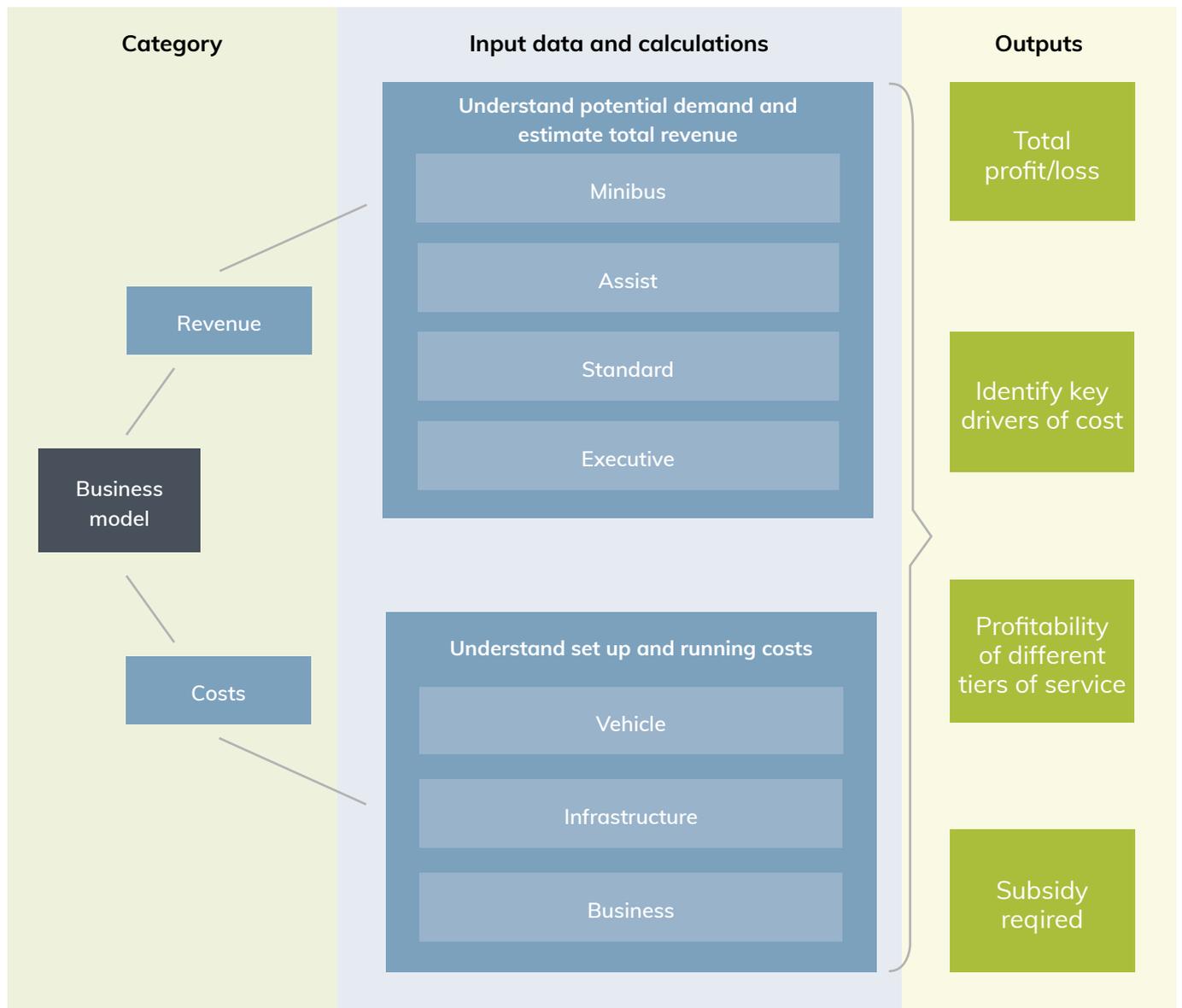
One of the common assumptions about AV ride-sharing is that the service will be cheaper to run and therefore cost consumers less. This is partly driven by the assumption that AVs will be electric and so enjoy lower costs of service, maintenance and ‘fuel’. It is also partly driven by the assumption that no driver will be required and therefore a significant labour cost saving can be made. This section of the report will share the likely costs and potential profitability of AV ride-sharing services which are designed in different ways. It will also comment on any

subsidies which may be required to support AV ride-sharing.

6.5.1 Operator costs

The business model built by MERGE Greenwich aimed to capture all running costs which would be incurred by an operator of an AV ride-sharing service. The model assumed the service provider was already established. Therefore, service running costs were treated as being incremental to an existing large-scale mobility business. If the full set up costs were included, the payback period would not be achievable in a reasonable time period.

Figure 17: The AV ride-sharing business model compared modelled revenue with costs



Cost category	Description
Vehicle costs	
Cost of the fleet	Up-front vehicle costs were assumed to be spread over the lifetime of the vehicle in operation
Service and maintenance	An annual cost was applied to each vehicle to cover service, maintenance and cleaning
Insurance	Insurance costs covered the AV and the service, including 3rd party damages
Data transfer	This included a hard drive on each AV to record a day's worth of data, and the ability to 'report back' to the operator on a daily basis
Refurbishment costs	The cost to refresh the interior of the vehicle covered repair or replacement due to wear and tear of the seats and/or in-cab technology
Residual value	A residual value was calculated for the fleet; however, the high utilisation leads to most vehicles reaching the end of their useful life within a 2 year period
Registration fee	The cost of registering each vehicle was captured in set up costs but was not applied to running costs

Infrastructure costs	
Depot space	An annual rental cost was assumed for depot space, which would be used to charge, service and clean the vehicles overnight
Depot fit out	Costs to refit depots to cater for electric and autonomous fleet vehicles were considered as set up costs and were therefore not part of the running costs which are included in this report
Depot staff	A cost for depot staff was included
Charger installation	A cost to install one 'Fast' (22kWh) charger per vehicle was captured in set up costs but was not considered as part of the running costs which are reported on in this paper
Cost of electricity	The cost to charge each vehicle overnight, plus an opportunistic 'Rapid' charge for the most heavily utilised vehicles, was calculated

Business costs	
Allocation and dispatch platform	The cost of maintaining an appropriate allocation and dispatch platform to assign AVs to passengers was included
Allocation and dispatch agents	A team of agents to support any anomalies with running the fleet was included in the cost model as experience has shown that a level of human intervention is always required in certain circumstances
Contact centre	MERGE Greenwich assumed a customer service team would be available 24/7 for AV passenger support; this included training and employing staff and providing office space for this team
On-board stewards	A cost for training and employing on-board stewards for the Assist service was included, assuming three people were required per Assist vehicle in order to cover all hours of operation
Digital customer experience	The annual costs for developing and maintaining an AV ride-sharing app, plus marketing and customer engagement activities were included
Marketing and CRM	The costs of customer engagement were captured to reflect the significant effort required to build and maintain customer trust while delivering the service
Service wrapper	Licensing, operator insurance, health & safety and a provision for fare evasion were all included in the business running costs
Margin	A commercial margin was applied to the Standard and Executive tiers of service. A very low margin was applied to the Minibus tier and no margin was applied to the Assist tier as it was assumed this service may be publicly funded

6.5.2 Is an AV ride-sharing service commercially viable?

MERGE Greenwich simulated three different service blueprints and tested the commercial viability of each one³⁹. The conclusion was that AV ride-sharing could be commercially viable for existing operators to implement, depending on two key factors: whether stewards were employed to accompany passengers and whether the cost of autonomous vehicles could reduce, to be more in line with conventional vehicles.

Revenue

The pricing objective of the MERGE Greenwich blueprints was to offer a range of services which preserved customer choice and delivered equitable transport across the Borough. Prices were also set relative to existing modes of transport to ensure in particular that the AV ride-sharing service was more expensive than a bus. The anticipated demand was then used to estimate revenue for each blueprint to determine whether profitability could be achieved or whether the service would need to be funded in other ways, such as government funding or new, alternative revenue streams such as monetisation of data.

When delivering a range of services at accessible prices on a small scale of demand, the simulated blueprints showed some parts of the service could possibly break even:

- The Minibus tier of service became profitable when a price increase of 90p was applied, taking the flat fare from £2.60 in the accessibility blueprint to £3.50 in the combined blueprint.
- The Assist service costs outweighed the revenues under all blueprints. This was largely due to the high expense of leasing an autonomous vehicle as well as the labour costs associated with providing a steward on board to provide assistance,

while offering the service at a low cost, accessible, flat fare of £2.60.

- The Standard and Executive tiers of service were profitable under the convenience blueprint when passenger choice was restricted to these and passengers had no lower cost alternatives. These tiers incurred a minimum fare of £5.00 and £6.50 respectively, and per km pricing thereafter. However, when a lower priced option (Minibus at a flat fare of £3.50) was made available under the combined blueprint, naturally the price sensitive segment of passengers who were previously not served gravitated to the lower priced tier of service at the compromise of travel convenience and longer waiting times.
- Demand for the top tier of service (Executive) was relatively small scale within the Borough under all blueprints, which is representative of today. However, as this tier required a large fleet to meet the target service levels and experienced low demand, it struggled to break even with inner-borough trips.

To improve profitability, services should be priced at a suitable level to capture the value they bring to the passenger, whilst also balancing the sensitivity to ensure sufficient passenger demand to justify commercially operating those services. Extending services beyond the Borough to offer inbound and outbound trips would also help with increasing demand and revenues from the services.

Labour costs

Contrary to a commonly-held assumption, labour costs cannot be removed from an autonomous vehicle service. Secondary roles which are currently carried out by the driver will need to be delegated to kerb-side or venue-based support (e.g. handling bags),

39. Note: the costs considered in the business model were operating costs only, this excludes set up costs which would be incurred by organisations which are not already operating a mobility service, such as the cost of allocation and dispatch software and back office support



the digital experience (e.g. trip preferences and information), contact centre support (dealing with an emergency, assistance or queries) and depot-based support (cleaning, maintenance, repair and charging). One particular role which is likely to remain, and which could improve the passenger experience, is an on-board steward to assist elderly, disabled or minor passengers, or as a premium option.

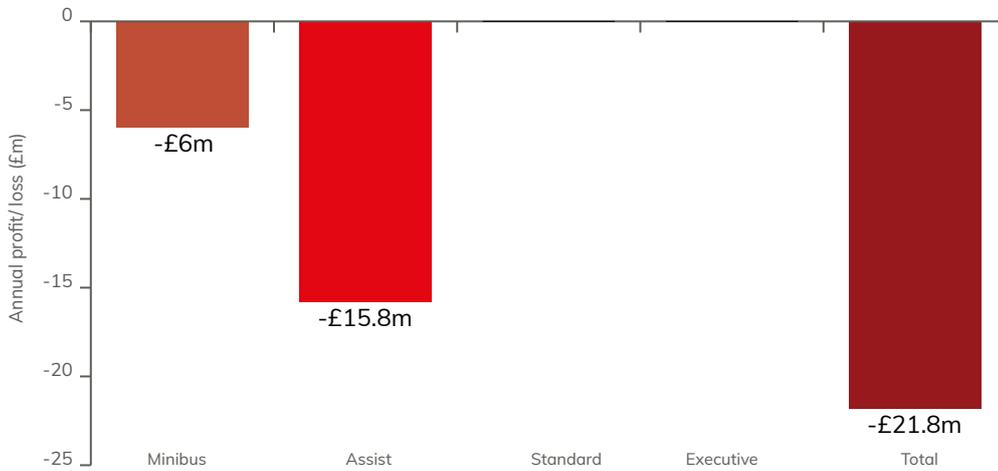
The Assist service developed in this project aims to provide an improvement on current Dial-a-Ride and TaxiCard services, both in terms of passenger comfort and price. The on-board steward in this service would be

available to help passengers enter and exit the vehicle and, unlike a driver, would be available to help the passenger during the journey as well.

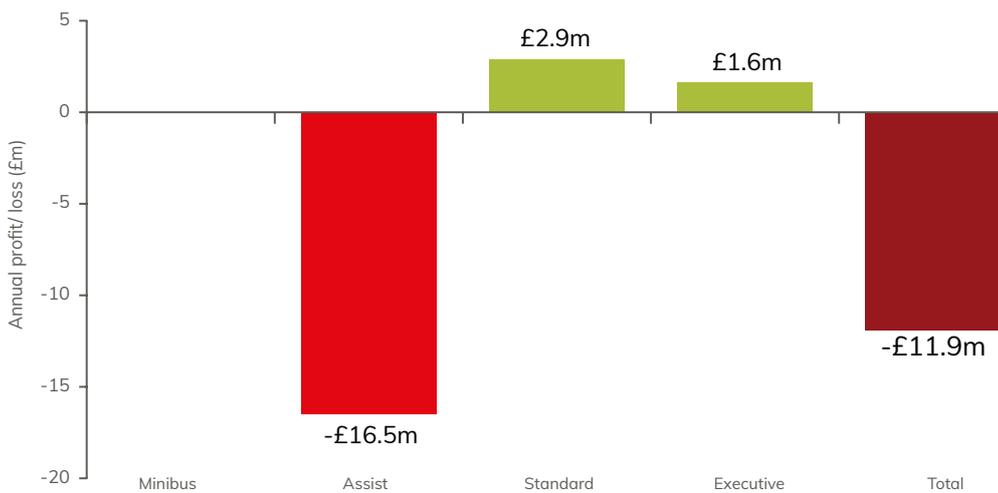
In our simulations, we applied a standard flat fare to evaluate the profitability of this service offering and to provide a comparison with the current services, mentioned above. MERGE Greenwich analysis suggests that the Assist service, largely due to the high cost of an on-board steward, is the only tier of service which is not commercially viable under any blueprint, as illustrated in Figure 18 below.

Figure 18: The Assist service is loss-making in each blueprint due to low flat fare and cost of the on-board steward

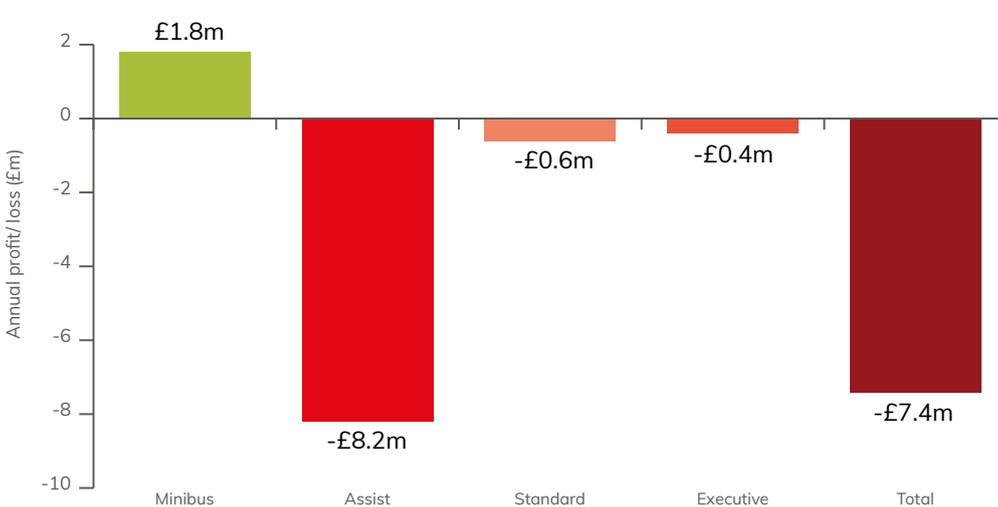
Accessibility blueprint: Annual profitability by tier



Convenience blueprint: Annual profitability by tier



Combined blueprint: Annual profitability by tier



This could indicate the need for a subsidy to ensure certain AV ride-sharing services do have a steward on board, so that passengers who require assistance can use the service.

The real cost of running the AV ride-sharing Assist service with an on-board steward is estimated to fall between £16 and £20 per trip. When compared to existing subsidised services, this appears to be a good alternative for cities aiming to deliver mobility services to older people and the disabled. Today, Dial-a-Ride services cost approximately £27⁴⁰ per passenger, per trip. TaxiCard users receive a per-trip subsidy of £8.30 and pay the remainder of the taxi fare which, depending on the trip duration, could be significant. When compared to these two services, AV ride-sharing Assist could be particularly attractive as it offers a number of further benefits, such as higher service levels, a more integrated booking platform and a trained steward to attend customers whilst the vehicle is on the move.

Vehicle costs

The other significant cost item in the AV ride-sharing business model is the cost of the vehicles. There is a high cost associated with first generation AV technology, as well as a high cost currently assumed for the EV technology required for those vehicles.

To reflect the fact that the cost of both AV and EV technology will reduce in the coming years, MERGE Greenwich modelled best and worst-case scenarios for vehicle costs. The 'best case' assumes second generation electric AVs, where cost efficiency of the technology has been improved and incorporated into production vehicles by 2025, whereas the 'worst case' assumes first generation electric AVs and cost assumptions based on today's technologies.

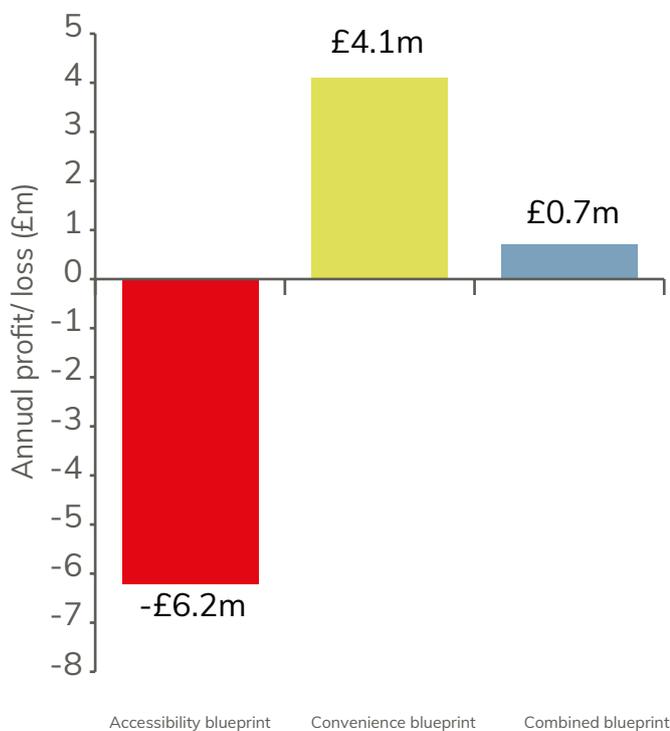
The charts opposite (Figure 19) illustrate the profit/loss of each modelled blueprint when the loss-making Assist tier has been excluded (as explained above, this tier of service significantly impacts the commercial viability of AV ride-sharing but may have a strong case for public subsidy). In this analysis, the 'worst case' costs support a positive commercial case for the convenience and combined blueprints, but not for the accessibility blueprint (estimated annual loss of £6.2m), which is the largest scale service and assumed the lowest fares. As this blueprint resulted in the largest fleet, the commercial viability was particularly sensitive to vehicle costs, resulting in a significant profitability improvement when 'best case' costs of 'next generation' electric AVs were applied (estimated annual profit of £3.9m).



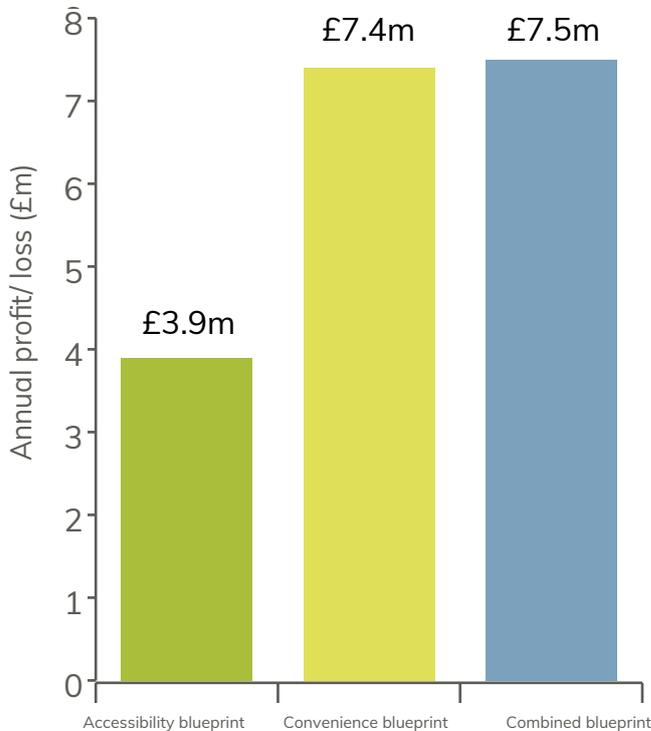
40. Dial-a-Ride costs TfL £35 million a year to deliver 1.3 million trips

Figure 19: Profitability of AV ride-sharing with best and worst case BEV costs (excluding assist tier)

Profit/loss with worst-case BEV/AV costs



Profit/loss with best-case BEV/AV costs



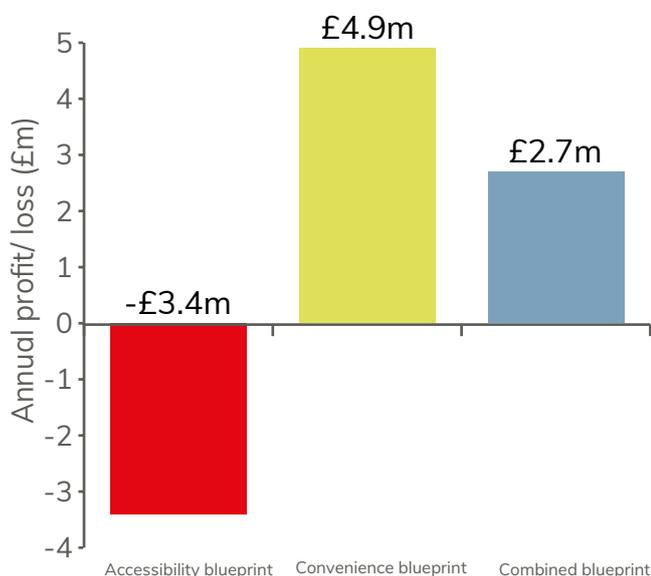
For pioneer providers of this type of service, there could be a positive role for plug-in hybrid vehicles (PHEV) which are less expensive than battery electric vehicles (BEVs) of medium to high electric range, albeit they do not offer the same emissions benefits. Figure 20 illustrates how the PHEV option improves the profit and loss balance for all

three blueprints in the ‘worst case’ vehicle cost situation. There is a significant fuel cost linked to the use of AV PHEVs, which has been taken into account, but this option could still provide a more positive business case compared to the BEV option, particularly in the interim period through to 2025.

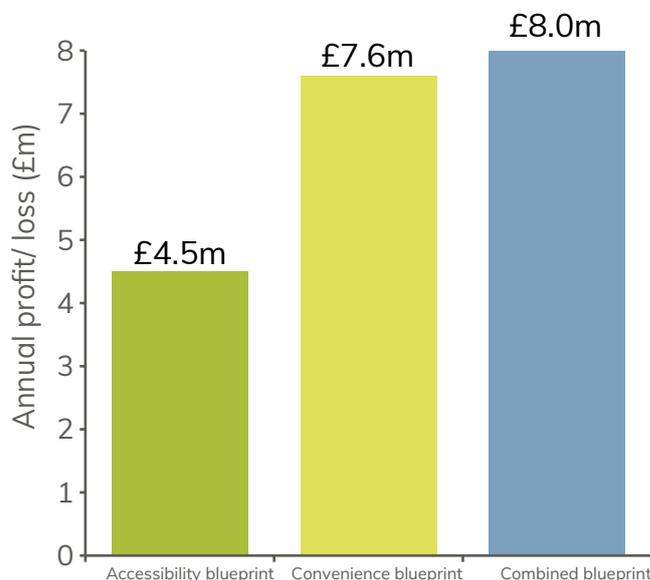
AV ride-sharing services can be commercially viable with ‘first generation’ electric autonomous vehicles, with the profitability expected to improve as the technology evolves. Plug-in hybrid AVs are another feasible vehicle option, which could offer some additional cost benefits in the interim period through to 2025.

Figure 20: Profitability of AV ride-sharing with best and worst case PHEV costs (excluding assist tier)

Profit/loss with worst-case PHEV/AV costs



Profit/loss with best-case PHEV/AV costs



Set up costs

MERGE Greenwich calculated the cost of setting up an AV ride-sharing service as well as operating costs compared to anticipated revenue. When considering the operating costs as an add-on service to a large scale operation, the analysis indicated an AV ride-sharing service could be commercially viable, particularly for the Standard and

Executive tiers of service, as demonstrated in the convenience blueprint. However, set up costs and the time taken to build customer engagement and scale are likely to be significant barriers to entry for new entrants or may require significant government subsidy. If full set up costs were taken into account the business model did not break even within a reasonable time-period.

AV ride-sharing services may be commercially viable for existing, large scale mobility providers which can benefit from economies of scale and are capable of meeting customer expectations. New entrants may find the time and set up costs to deliver this service are prohibitive.



7. Conclusions and recommendations

7.1 What is the blueprint?

MERGE Greenwich tested whether AV ride-sharing could contribute towards the vision for Mobility as a Service. Three service blueprints were designed and simulated in order to assess which type of service would contribute the most towards the future vision of delivering greener, more efficient and more accessible mobility solutions for cities and citizens.

Testing each blueprint resulted in both positive and negative outcomes. On balance the combined blueprint offers the most beneficial combination of results. The combined

blueprint was a design based on lessons learnt from the accessibility and convenience blueprints and variations on each. Elements of the service were adjusted in order to achieve large scale uptake, minimise modal shift from public transport, address mobility gaps, provide maximum customer choice and improve commercial viability.

The table overleaf summarises the impact of each blueprint and demonstrates that whilst the accessibility and convenience blueprints produced the best or worst results, the combined blueprint offered the optimal balance across all aims:

Hypotheses		Base case (excluding AV ride- sharing)	Accessibility blueprint	Convenience blueprint	Combined blueprint	Which blueprint is most beneficial?	Second best blueprint
Will demand for an AV ride-sharing service be high? (% of daily trips using AV ride-sharing)		68% of trips could, in theory, be shared	28%	8%	16%	Accessibility	Combined
Will AV ride-sharing achieve high vehicle utilisation?	% vehicle utilisation	-	70%	50%	68%	Accessibility	Combined
Will there be modal shift to AV ride-sharing?	From public transport	-	34%	8%	19%	Convenience	Combined
	From private cars	-	14%	6%	8%	Accessibility	Combined
Can AV ride-sharing address mobility gaps by reducing journey time?	% reduction in journey time to transport hub	~22 mins	75%	76%	27%	Convenience	Accessibility
	% reduction in journey time in poorly connected areas	~23 mins	53%	74%	21%	Convenience	Accessibility
Will Av ride-sharing offer social benefits?	% increase in traffic (total kms)	-	57%	20%	37%	Convenience	Combined
	% reduction in trips requiring parking	-	38%	16%	25%	Accessibility	Combined
	% increase in CO ₂	-	24%	5%	15%	Convenience	Combined
Will AV ride-sharing be commercially viable?	Annual subsidy required (including Assist tier and assuming worst-case BEV/AV costs)	-	£21.8m	£11.9m	£7.4m	Combined	Convenience

Overall, the combined blueprint offered the most benefits

Based on the results of the combined blueprint, MERGE Greenwich would suggest that the following features should be part of real-world AV ride-sharing service designs:

- Provide a range of services to meet different customer needs and preserve customer choice
- Achieve an economy of scale by aiming for city-wide services or by serving a wide number of geo-fenced locations to ensure commercial viability
- Ensure the service offers a level of convenience and flexibility which is attractive to private car users
- Provide an option for an on-board steward – either for assistance or as a point of service differentiation
- Tailor each tier of service by balancing convenience (waiting and detour time) with cost
- Size the fleet to encourage a high level of sharing and vehicle utilisation
- Price AV ride-sharing services at least double the fare of buses to minimise switching from public transport
- Attract car owners to use the service and reduce the demand for parking spaces, which could enable valuable urban space to be re-purposed

7.2 Recommendations for optimising the blueprint

The combined blueprint offers the optimal combination of results but it is clear that a number of outcomes could be improved. Research indicated that service design can go some way to optimising the impact of AV ride-sharing but external factors also have an important influence.

Recommendations for further improving outcomes are below. A full set of wider recommendations for implementing an AV ride-sharing service are included in Appendix 1.

1. Increase demand for AV ride-sharing by:

- **Rolling out a public education campaign now:** Raising awareness of AVs and ride-sharing through campaigns and customer engagement could encourage greater uptake of the service and will be essential to ensure road users are ready to interact safely with the new technology when it becomes available.
- **Developing purpose-designed vehicles:** Ride-sharing is the key barrier to uptake for this service. Customer research highlighted vehicle design would go some way towards alleviating these fears. Designs could include large windows, in-vehicle communications, frequent opportunities to exit the vehicle, optional steward on board, emergency call button and the use of customer feedback/ratings.
- **Including induced demand and focus on a wider geographic area:** The MERGE Greenwich simulation assumed no induced demand and focused only on the Greenwich area. However the introduction of flexible, low-cost, on-demand services may increase the total demand for transport. Moreover, the benefits of AV ride-sharing could probably be further emphasised if longer, multimodal trips are included in the simulations. A wider test area would allow the testing of more complex scenarios and thus produce more insightful results.

2. Reduce modal shift from public transport by:

- **Incentivising the use of AV ride-sharing along with public transport:** Offer incentives for passengers who use AV ride-sharing to reach mass transport hubs and continue their journey using mass transit to encourage adoption of the service in a way which 'feeds' public transport rather than competes with it for end-to-end journeys.
- **Applying a minimum fare to reduce the use of AV ride-sharing for short trips:**

Fares which are more than double those of public transport will be required to reduce switching from buses and discourage the use of AV ride-sharing for short distances which could be walked or cycled.

- **Continuing to invest in walking and cycling:** To support the minimum fare which deters passengers from using AV ride-sharing for short trips, continued efforts to improve facilities for walking and cycling are required to make these modes the most attractive for shorter distances.

3. Improve efficiency of the service by:

- **Creating synergies with public transport routes and hubs:** Ensuring interchanges between existing mass transit systems and new modes of transport are smooth will help AV ride-sharing be an effective 'feeder' for public transport hubs. This will involve routing services to hubs, booking and payment systems integration as well as reallocating space, such as converting rail station car parks to pick-up and drop-off bays.
- **Specifying pick-up and drop-off points to encourage walking, reduce vehicle kms and reduce congestion:** Use allocation and dispatch logic and map pins to specify nearby pick-up and drop-off points which encourage passengers to walk the final steps to and from meeting points. This will also help improve the convenience for passengers sharing trips, by helping to reduce travel and detour time.

4. Reduce the impact on congestion by:

- **Making private car usage less attractive:** For AV ride-sharing to have a positive impact on congestion, a net reduction in kms is required. This means the new service would need to attract a significant proportion of passengers to switch from private cars, rather than from buses. Policies which increase the cost and/or inconvenience of private car usage,

such as parking or road pricing, would accelerate the shift to sustainable modes, including AV ride-sharing.

5. Reduce emissions by:

- **Ensuring the fleet is electric and uses renewable energy:** In addition to measures above which would reduce the total kms by supporting a greater level of switching from private car users (especially from internal combustion engine vehicles), AV ride-sharing services can have a positive impact on emissions by ensuring the fleet is fully electric and charged using renewable energy.

6. Improve commercial viability by:

- **Increasing scale:** AV ride-sharing services could cater for more shared trips and be more profitable if operated in a larger area than that represented by Greenwich. Whilst this project only considered trips within the Borough, simulations could



demonstrate how the demand for ride-sharing could increase if a broader range of pick-up and drop-off locations were offered, catering for inbound and outbound travellers. Increasing demand in this way would improve the utilisation of the fleet and make the service more profitable.

- **Testing the impact of pricing on demand:** Applying surge pricing and/or price reductions to influence behaviour, such as offering a discount for passengers who are willing to wait, should be investigated to understand the potential impact on demand. Similarly, subscription models and loyalty schemes should be explored to identify whether an increase in price could improve profitability.
- **Focusing on cost per mile:** Given the high cost of early generation AVs, vehicle manufacturers are urged to work with mobility service providers in order to

develop financing solutions which help to manage cash flow and minimise the cost per mile as far as possible. This will help increase certainty and offset the initial high price of the first-generation technology. This could include broader fleet managed services, such as providing vehicle servicing, maintenance and in-cab refurbishment for the entire fleet.

- **Considering plug-in hybrid vehicles which may lower short term costs:** For pioneers of AV ride-sharing services, the slightly lower cost of plug-in hybrid vehicles (PHEV) could provide a more commercially viable alternative to battery electric vehicles, although this would not offer the same emissions reduction opportunity.

7. **Develop a clear city vision for Mobility as a Service to guide private and public developments and ensure alignment to city goals by:**

- **Underpinning the vision with a set of targets:** These targets must balance the needs of the city, the consumer and the operator. MERGE Greenwich has shown that implementing a service which is designed to achieve a particular goal can have extreme positive and extreme negative outcomes. However, a service which is developed to achieve a broad set of objectives will, overall, deliver greater benefits to all parties. If policies and measures are also aligned to this vision, the opportunity is created to accelerate deployment of new services to support the city.
- **Increasing the level of collaboration between industry and government:** For this to happen, government and industry organisations need to collaborate extensively and jointly develop the vision and the objectives. This ensures buy-in and alignment of all stakeholders, achieving a vision which balances city needs, citizen needs and public and private enterprise.



8. Final remarks and key recommendation

MERGE Greenwich set out to develop a blueprint for an autonomous vehicle ride-sharing service which integrates with public transport. The aim was to research, design, simulate and test a new service which could, by 2025, contribute towards a vision for Mobility as a Service by providing greener, more efficient and more accessible transport for citizens.

Will the vision for the future of urban mobility of integrated AV ride-sharing deliver on this promise? MERGE Greenwich concludes it is possible.

However, if introduced without the right framework for integration and synergy with existing transport modes, such a new service could have unintended consequences. It could lead to an increase in traffic and emissions. It could also manifest as an inequitable service which supersedes or competes with public transport.

Key recommendation

The recommendation from the MERGE Greenwich Consortium is that central government needs to bring a dedicated focus to the roll-out of new services, such as AV ride-sharing, to ensure they align with the vision for transport and the city-wide agenda. To achieve this, government should:

- Set out a clear vision, strategy and goals for the introduction of AVs and ride-sharing services in cities
- Determine appropriate measures which, over time, mark the progress towards these goals
- Develop a roadmap to guide the introduction of new services, ensure they align with the vision and help organisations to deliver solutions which cater for the needs of the city

To help achieve this MERGE Greenwich recommends that the government create a City Mobility Taskforce with the following included in its mandate:

- To set out the vision and plans for the introduction of autonomous services
- Engage with and educate the public on ride-sharing and autonomous vehicles
- Introduce policies which encourage the right modal shifts
- Set out changes and guidelines for infrastructure planning and investment
- Assess how best to use and align autonomous vehicle trials in achieving the vision

Putting this taskforce in place now will help avoid unintended consequences, by taking a proactive approach and forward planning for the introduction of autonomous vehicle ride-sharing.

The time to plan for AV ride-sharing services is now. MERGE Greenwich developed sophisticated simulation and modelling tools to accelerate the understanding of how autonomous vehicle ride-sharing services could impact our major cities. As well as achieving benefits, the simulated blueprints led to outcomes that could be detrimental to the city. Taking a proactive approach to planning the introduction of new services to achieve synergies with existing transport services will help minimise any unintended consequences.

The MERGE Greenwich project has signposted many of the next steps required by cities, governments, mobility operators and automotive technology providers to deliver autonomous vehicle ride-sharing in a way that can deliver benefits city-wide. Using these findings and assets will pave the way for the introduction of AVs in a ride-sharing capacity in the future.





9. Appendices

Appendix 1: Further recommendations for optimising AV ride-sharing services

The recommendations in this report aim to highlight the key considerations for government and industry with regard to the introduction of AV ride-sharing. MERGE Greenwich simulations have illustrated that the way services are designed can significantly influence their societal and commercial impact. For this reason, the suggestion is to accelerate the collective learning in this area in order to ensure that next generation mobility services are developed and delivered in a way which helps, rather than hinders, cities.

A1.1 Recommendations for mobility service providers

These recommendations are aimed at large scale mobility providers because MERGE Greenwich analysis indicated that set-up costs may be prohibitive for new entrants. As such, it is assumed the most efficient and cost-effective route to mass roll-out of AV ride-sharing services will be through established, large-scale mobility operators who can implement this as a 'bolt on' service.

Specific recommendations for mobility providers include:

- Start thinking about the adoption of ride-sharing and autonomous vehicle technology now; large scale manufacturers

have indicated AVs could be available for commercial roll-out as early as 2021. Having spent a year considering MERGE Greenwich, the consortium acknowledges that the breadth and depth of knowledge, along with the time to engage key stakeholders, required to develop these new services is significant.

- Recognise the role and responsibility your organisation could take on, and the opportunity this might present, to accelerate the development of next generation mobility solutions which will help cities overcome challenges and achieve societal goals.
- Carry out customer research to understand whether ride-sharing is relevant to your customer base and lends itself to certain missions and, if so, plan to investigate the introduction of a service alongside existing offers to assess interest and uptake.
- Consider electric and autonomous vehicles within the roadmap of fleet developments and seek to gain early experience with products through partnerships with technology and automotive providers.
- Support work by technology and automotive providers who may need to gather technical data from your existing fleets to create mapping information. This is a pre-requisite to the introduction of autonomous vehicles and is potentially a new revenue stream.
- Consider collecting and sharing data with transport authorities to demonstrate the value of the service and provide continuous evaluation on performance.
- Review the potential impact of autonomous services on the operational model and cost base, and assess all areas of the organisation to ensure customer service and experience are preserved; for some missions an on-board steward or 'concierge' may be required. Other roles which are currently carried out by

the driver may need to be delegated to digital or back office support services as an evolution from today's operation.

- Collect data that enables vehicle manufacturers to develop AV technology and consider commercialising this data.
- Seek to work with regulators to help shape policies that enable the introduction of new technology and services, whilst preserving the safety of the public and passengers.
- Contribute to generating awareness and understanding among customers of the possibilities which autonomous technology and ride-sharing services present, to help pave the way for the introduction of AV ride-sharing.
- Work with vehicle manufacturers to develop bespoke ride-sharing vehicles which address concerns regarding ride-sharing and enhance the customer experience through internal cab design and communications and/or surveillance systems. Willingness to ride-share is a limiting factor for this type of service and it will require more effort to address this barrier than to overcome concerns regarding AV technology.
- Consider your organisation's role in a city-wide MaaS system – this may mean owning the whole service end-to-end for your traditional services, extending the operation to cover other modes of transport, being a supplier to a third-party platform or a combination of all of these.
- Place emphasis on building an integration capability within your business, as this takes time; being able to technically integrate with a MaaS platform is key to enabling a service that could cross different modes of transport.
- Consider gamification when planning app developments. Such measures could be a powerful influencer of behaviour

and modal choice; for example, an app which awarded 'points' to customers who chose to walk, when they could have used AV ride-sharing, would encourage healthy habits and help achieve wider city objectives.

- Seek to create a differentiated customer experience and good customer engagement through digital platforms, customer service, loyalty initiatives, CRM engagement and in-car technology; if it is not already, this may become the primary channel for engaging with customers.
- Consider prices for AV ride-sharing which are above those of public transport, as this will significantly reduce mass switching from bus and tube services.
- Consider the role of PHEVs in the fleet.
- Consider connected car technology and how this could support an integrated traffic management strategy in cities.

A1.2 Recommendations for vehicle manufacturers

The MERGE Greenwich research revealed a number of insights which vehicle manufacturers may wish to consider when designing next generation AVs. These recommendations include:

- Consider customer attitudes, motivations and concerns regarding ride-sharing and design the vehicle accordingly. The focus should be on vehicle design and features, which enable a unique journey experience for the customer. This will require further research but early indications show that large windows, seating which is configured to be more like public modes of transport than a car and in-vehicle technology to connect the passenger to the infotainment system maybe be required. Further details can be found in the MERGE Greenwich report on attitudes to AV and ride-sharing⁴¹.

- Purpose-built vehicle design extends to the technology inside the vehicle as well as the size, shape and configuration of the vehicle. For example, the vehicle will need to provide a passenger validation method to ensure the customer was the right person, that they had paid and that no-one followed them into the vehicle. This system will also require a clear protocol to enact should that happen.
- Consider the technical interface which will be required between the service operator and the vehicle. This may require an additional level of data transfer to ensure the AV can maintain communication with the operator at all times, as well as process real-time information such as traffic diversions and weather conditions.
- Explore vehicle financing options with service providers, for example a cost per km rather than traditional, fixed term, lease arrangements. The transition period from service introduction to steady-state, which is associated with higher AV/EV technology costs, will require operators to take on significant development costs, so these innovative solutions may be a way to break down the up-front cost in a more commercially viable way.
- Extend the collaboration with operators to consider the secondary market for AVs. It is not clear whether there will be a residual value for AVs or whether the early AVs will have the capability to revert to human-driven vehicles in order to be suitable for a secondary market. As this has such a significant impact on the profitability of the service, it is worth careful consideration.
- Explore additional routes of revenue, for example through data monetisation, and configure the vehicles accordingly. A business model may be related to creating high-definition digital maps from the fleet, which can form or contribute to a digital product closely linked with developing AV technology.

41. www.mergegreenwich.com/city-compatibility-how-av-ride-sharing-could-be-implemented

- Understand how operators can help create maps and data which support AV development.
- Work with service providers to design purpose-built ride-sharing vehicles.
- Government should continue to provide appropriate support to AV ride-sharing pilots, trials and demonstrations to enable them to move from concept to market.
- Government should work with existing economic, environmental and safety regulators to create a safe, flexible and pragmatic regulatory system that enables and incentivises the delivery of AV ride-sharing.

A1.3 Recommendations for government

AV ride-sharing must be designed, developed and delivered as part of the Mobility as a Service vision. If left unchecked, there is a danger that this type of service could be designed in isolation, with unintended consequences for the city.

The role of national and local governments will need to evolve in order to guide and enable the development of AV ride-sharing services which improve passenger choice, convenience and accessibility. Since MERGE Greenwich believes that well designed and appropriately deployed AV ride-sharing services have the potential to improve mobility significantly, governments must ensure that infrastructure, safety, regulation and price all keep pace with demand and growth of AV ride-sharing.

In order to achieve these, MERGE Greenwich recommends the following:

National government

- The National Infrastructure Commission should consider the role of AVs in the design and delivery of significant infrastructure projects (NSIPs). Given the length of time required to deliver major infrastructure projects and their legacy as assets, it is vital they do not lock out future technological innovation and requirements.
- The National Policy Planning Framework should be reviewed and updated to ensure that it is fit for a future that includes AV ride-sharing. This framework must provide a standardised national framework for AV ride-sharing delivery at a local level.
- Through the Future of Mobility Grand Challenge, government should work with mobility providers, OEMs, insurers and technology providers to develop an integrated and interdependent approach to the delivery of AV ride-sharing.
- Consider subsidising an Assist type service which provides an on-board steward for any passengers who require assistance, for example with wheelchairs or chaperoning. This could be a more cost-effective alternative to services such as Dial-a-Ride and Taxicard.
- Lead a public education campaign to increase awareness and understanding of AVs and ride-sharing. This should not only aim to encourage the uptake of ride-sharing but also educate pedestrians and cyclists on how best to interact with AVs.
- Apply policies to discourage private car usage, such as road pricing and parking charges. MERGE Greenwich modelling proved that introducing parking costs significantly reduced private car usage and it is reasonable to believe the same would be true for road pricing and other measures which increase the cost and inconvenience of private motoring. This could be part of a wider package of policies to prioritise and reallocate road space for sustainable modes.
- Work with service providers to understand how AV ride-sharing could enhance public transport services rather than threatening

demand for them. AV ride-sharing could be a cost-effective way to address mobility gaps. This may have significant social benefits (such as increasing accessibility which allows residents to remain in their own home without the need for support). These benefits may not traditionally be quantified when assessing transport solutions but could provide a compelling case for support if analysed appropriately.

Regional government and local authorities

- Combined and local authorities should adopt a standardised approach to AV ride-sharing technology and service delivery to ensure that services are interoperable.
- Work with mobility service providers to identify the road network over which the AV ride-sharing vehicles will be able to operate and where they can provide the greatest benefit. This may require changes in infrastructure, speed limits or other restrictions that will affect the area of operation.
- Urban planning may require a new approach to reallocate space on-street and at transport hubs to ensure there is sufficient space for pick-up and drop-off points at key origins and destinations.
- Where AV ride-sharing services could offer a more effective mode of transport than current public transport services, such as buses, local authorities must ensure that local communities benefit from improved services that are accessible to all.
- AV ride-sharing should be considered as a key part of Local Industrial Strategies.
- Local authorities are encouraged to carefully consider developing road infrastructure with a view to the adoption of AV ride-sharing.
- Local government could consider the role of road user charging, vehicle sharing and

ultra-low emissions zones to incentivise and enable a shift from private car usage to AV ride-sharing.

A1.4 Collaboration between industry and government is key

To ensure that the combination of AV technology and the emerging ride-sharing service can deliver the potential benefits on offer, it will be increasingly important for industry and government to work together. MERGE Greenwich is calling for a City Mobility Taskforce to be established, which would need to:

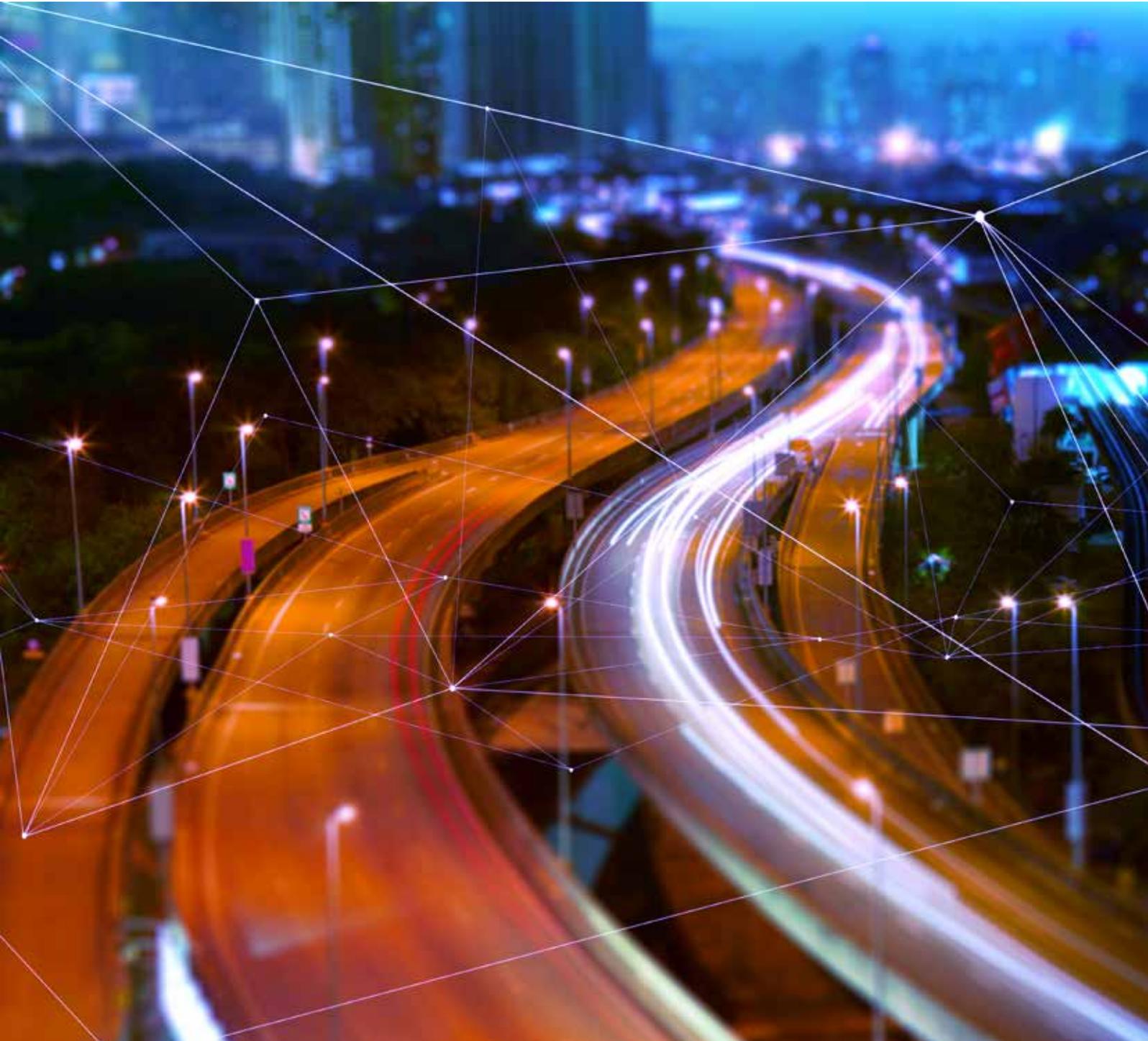
- Set out the vision and plans for the introduction of autonomous services
- Engage and educate the public on ride-sharing and autonomous vehicles
- Introduce policies which encourage the right modal shifts
- Set out changes and guidelines for infrastructure planning and investment
- Assess how best to use and align autonomous vehicle trials in achieving the vision

Integrating AV ride-sharing services with public transport will be an essential element of ensuring the new service does not compete directly with existing modes of transport. This will require integration at all levels – from the back-office systems to customer engagement and service delivery. In addition to integrating a new service, this process could also improve transport interchanges which would, in turn, improve the efficiency of mass transport as a whole.

MERGE Greenwich would strongly recommend the use of demand models coupled with fleet simulations in order to test solutions and assess impacts. This will de-risk strategic decisions and ensure that the roll-out of new technology and new services can be achieved smoothly and successfully.

As with all major developments, forward planning will deliver short and long-term benefits. The MERGE Greenwich consortium would strongly urge industry and government stakeholders to accelerate the formation of regulation to address some of the barriers set out in the implementation report⁴². This will include the need to identify suitable areas of

operation for AVs in the short, medium and long term, as well as to develop policies, regulation and public education campaigns, which will enable the mass adoption of AV ride-sharing. If achieved successfully, this initiative will help UK PLC remain at the forefront of AV development and deployment.



42. www.mergegreenwich.com/city-compatibility-how-av-ride-sharing-could-be-implemented

Appendix 2:

Suggested further research

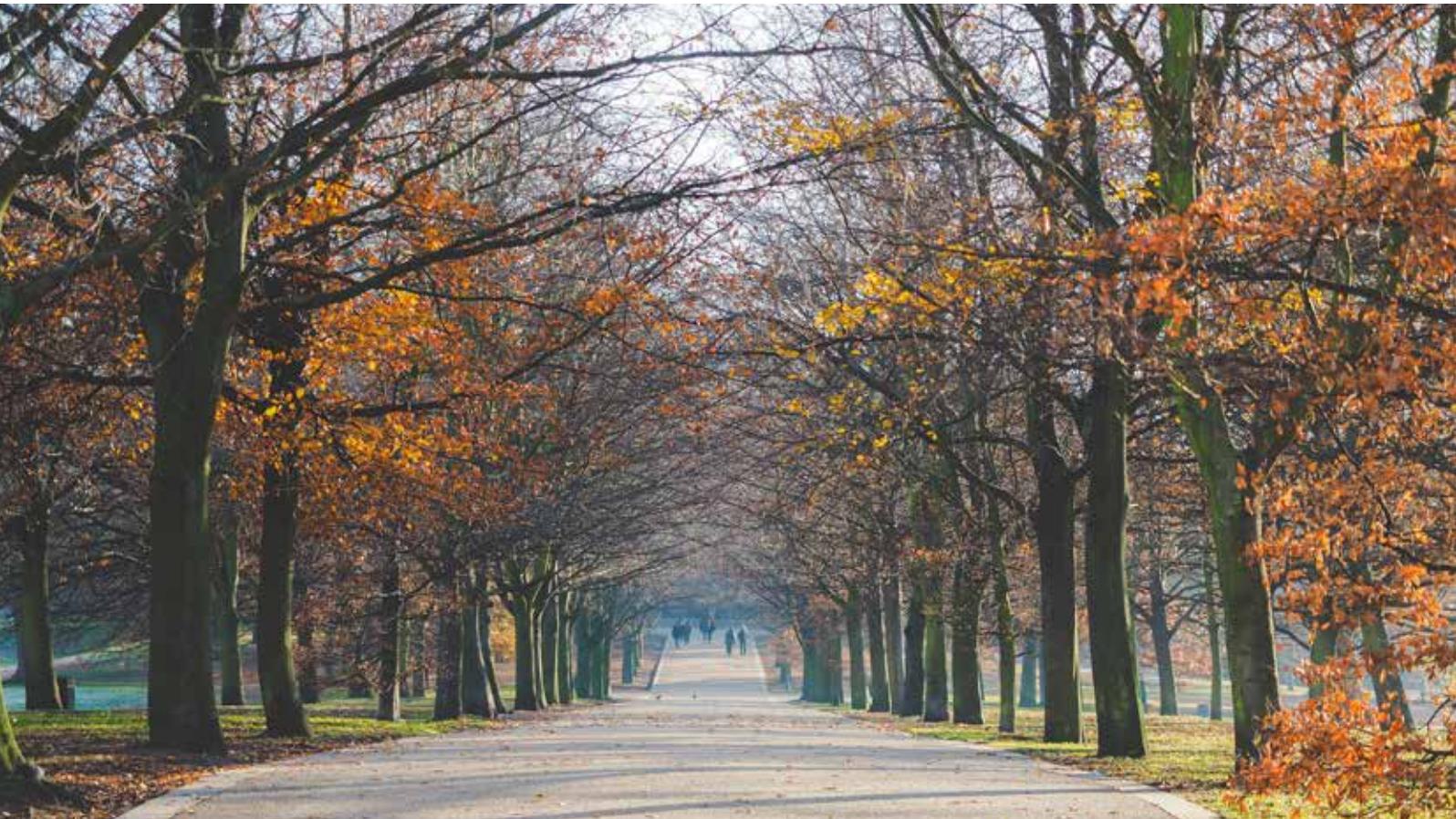
MERGE Greenwich has developed innovative and sophisticated multi-modal modelling tools. These tools can be used to design a wide range of different types of AV ride-sharing services which can be tailored to local needs, using different pricing structures, restricted operating networks, alternative traffic speed and flow blueprints etc.

The MERGE Greenwich consortium would welcome any enquiries about using these tools and suggests the following areas warrant further investigation:

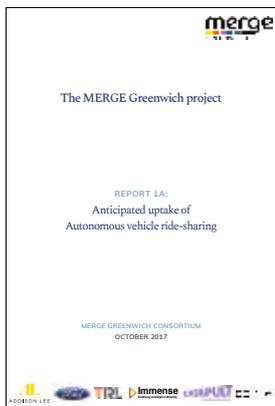
- Re-run the exercise for the whole of London to test the impact of scaling the service: because the demand modelling was only undertaken for trips within Greenwich it is not currently reflecting the number of trips that could be shared if a wider geographical area was considered. Also, AV ride-sharing would compete less with cycling and bus use, and more with private car use, if offered over longer trips.
- Re-run the exercise for locations outside urban areas (rural and suburban and inter-urban environments) to assess the impact on other types of community.
- Extend the model to include additional modes, in particular cycling and walking, multi-stage trips and rail which will be needed if larger geographical areas are considered.
- Look at the impact of implementing a range of different transport demand management policies, such as road user charging, parking restrictions, reallocation of road space and prioritisation of sustainable modes.
- Modelling of restricted AV ride-sharing networks, i.e. considering the likely situation that AVs would not be able to use the full road network without restriction during the earlier years of implementation, so operation might be confined to defined corridors or zones, potentially with speed or other restrictions on both AV ride-sharing and human-driven vehicles.
- Limited courier data was available for this study: it would be interesting to re-run the exercise to develop a similar strategy for courier services; it may also be feasible to combine passenger trips and parcel delivery, resulting in greater efficiency, fewer vehicles, less congestion, etc.
- It would be helpful for government to know whether AV ride-sharing could create additional demand for this form of transport; for example, people who currently find it difficult to get out of their homes may be encouraged to use the Assist type of service.
- Test wider society benefits: the availability of AV ride-sharing, in particular the Assist service, could lead to older and/or physically frail people being able to stay in their own homes for longer. There may also be other benefits which go beyond transport and may not traditionally be captured when making transport decisions.
- Further research into exactly how many people could share particular trips would be useful when considering the integration of different transport modes. Initial modelling by MERGE Greenwich showed that small groups of 2 to 8 people would be able to ride-share, as their journeys began within a five-minute window and

had similar pick-up and drop-off locations. This indicates AV ride-sharing could be ideal for the Minibus service and would not compete with existing bus services, but this needs to be investigated in more detail.

- Further analysis on price sensitivity and how it varies between different groups and locations, building on MERGE Greenwich sensitivity analysis and the stated preference research already undertaken for the GATEway project.
- More research to build a clearer picture of customer preferences and personas; MERGE Greenwich needed to consider only a limited number of options for the purposes of this initial study and a larger sample size would increase the insights regarding customer preferences.
- Look at different types of vehicles; MERGE Greenwich recommends four tiers of service catering for different types of customer with different expectations on service, price point and level of sharing. There may be other needs and expectations which were not captured during this piece of research and it would therefore be valuable to analyse the impact of adding further tiers to fulfil other needs and possibly create more demand.
- Assess different revenue streams which could be enabled by connected and autonomous vehicles, which could add value to the city and/or passengers and may support the commercial case for such services (e.g. look into the value of anonymised, aggregated data to the borough and city hall for transport policy and planning; or in-vehicle services which help passengers make better use of their journey time).



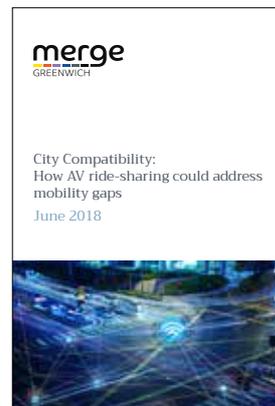
Research reports



Anticipated uptake of AV ride-sharing
Led by Addison Lee



Attitudes to AV ride-sharing
Led by DG Cities



City compatibility: how AV ride-sharing could address mobility gaps
Led by DG Cities



City compatibility: how AV ride-sharing could be implemented
Led by TRL

Other assets



MERGE Greenwich project findings
Led by Addison Lee



Digital customer experience mock-ups
Led by Addison Lee



A blueprint for autonomous ride-sharing services
Led by Addison Lee

Consortium members



www.mergegreenwich.com

Consortium members

