Report 3 / 2017 NTNU IBM

Autonomous E-Mobility as a Service

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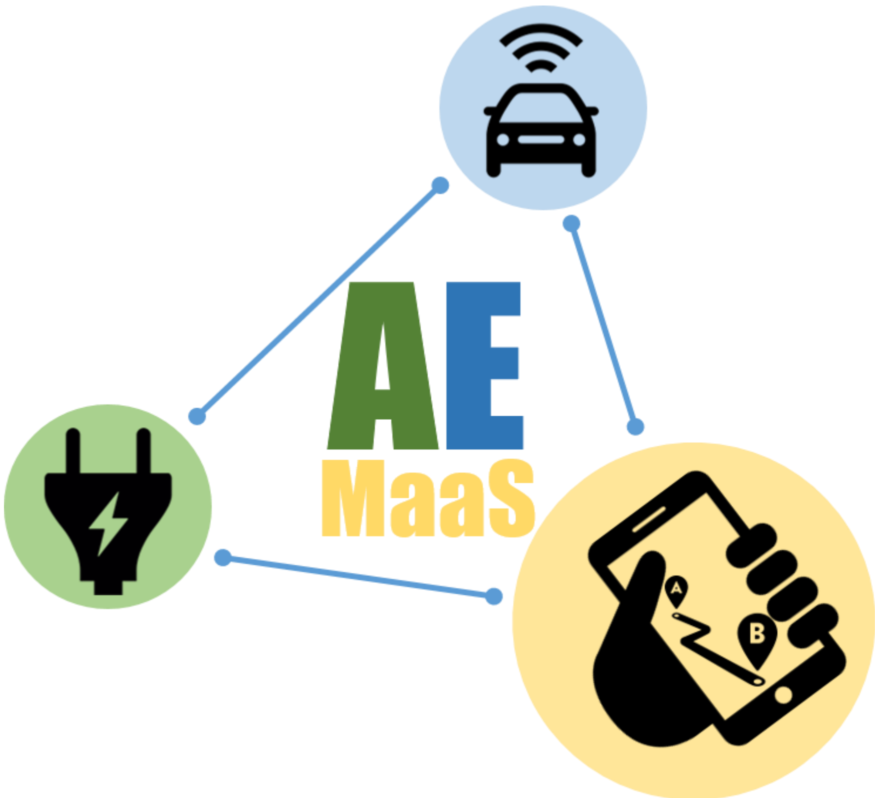

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Documentation

Title: Autonomous E-Mobility as a Service	Report number: 3
Authors: Kelly Pitera, Giuseppe Marinelli	Publisher: Norwegian University of Science and Technology (NTNU)
Funded by: Climate - KIC	Projekt number: -
Theme: Mobility as a Service	Date: 20. desember 2017
Subject: Transport Analysis	Number of pages: 47
Keywords: MaaS-system, Electric vehicle, autonomous mobility,	

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SUMMARY

Mobility as a Service (MaaS) is a systems-oriented approach of integration of numerous transport services into a single, seamless mobility service using a technology platform. Building on MaaS to incorporate both electric and autonomous mobility, the concept of Autonomous E-Mobility as a Service (AE-MaaS) is examined within this project as a way to improve the environmental sustainability of urban mobility. Through a series of workshops and meetings, the aim was to understand the feasibility of an AE-MaaS system, identify critical elements of AE-MaaS development, and understand how to ensure that sustainability is reached when developing AE-MaaS systems. Two AE-MaaS scenarios were considered, focusing on differences in the first/last mile autonomous component of the system, one being a fixed route service, the other being an on-demand service. The scenarios were considered through different perspectives of cities and citizens, context and economics, and vehicles and MaaS technologies.

The concepts of (1) communication and data transfer within a technical framework, and (2) needs and wants of users were identified as areas where more knowledge and experience is needed in order to build a successful AE-MaaS system. Understanding the needs and wants of users is specifically important if the goal of an AE-MaaS system is to improve the sustainability of urban mobility, largely through the reduction of personal vehicle miles travelled. As environmental sustainability within an AE-MaaS system is not a guarantee, the public authority is likely to need to take an active role to secure sustainability, either by taking an active role in the development of the system, or instituting procurement policies which require and/or reward sustainability within a private system.

The demonstrations and adjacent projects discussed within the report illustrate that the technology is developing rapidly and largely accepted by the public, public authorities are interested in implementing MaaS concepts, and there are potential markets where an AE-MaaS service could motivate people to move from their personal vehicles to more sustainable mobility options. To fully demonstrate and validate an AE-MaaS system, legal acceptance of autonomous vehicles is required. At the same time AE-MaaS is dependent on the timeline of advances in autonomous technology.

The ideas developed and discussed within the AE-MaaS Pathfinder project must be narrowed down and specified for a specific need and location in order for a successful demonstration. There are still questions related to the information technology platform, travel behavior and acceptance of AE-MaaS users, and full financial feasibility of the system, which should be further explored before and within a demonstration scenario.

This study was funded through the EIT’s Climate KIC Patherfinder Program.

CONTENTS

1. Introduction

Urban areas are faced with increasing transport demands coupled with increasing environmental concerns related to local air pollution and global greenhouse gas (GHG) emissions. Urban areas account for 60 to 80% of global energy consumption and GHG emissions (European Commission, 2017). Transport represents nearly 25% of Europe's GHG emissions, of which a quarter is caused by urban transport (European Commission, 2017). Over 60 % of transport-related emissions is caused by transport of persons (European Environmental Agency, 2013). To reach the EU's climate goals, European cities need to decrease their GHG emissions by 40% by 2030 (European Environmental Agency, 2016). Innovative solutions are needed to better utilize existing infrastructure in order to improve the efficiency of the transportation system and address sustainability concerns. Our current, predominantly fossil fuel-based, urban transport systems are highly reliant on personal vehicle travel, and need to be reconsidered as we aim to address future urban mobility challenges.

Public transport is often considered an essential component of sustainable urban mobility. In reducing dependency on personal vehicles by providing a competitive alternative to private cars, a collective public transport system can reduce adverse "auto-oriented" impacts such as air pollution and congestion (Miller, de Barros, Kattan, & Wirasinghe, 2016). While public transport provides a more sustainable solution than private vehicles, it does not adequately cover all urban mobility needs, due to a lack of flexibility and the "first/last mile" connection problem (travel between origin/destination and the public transport system). Thus, mobility innovations which improved on and build upon existing public transport are worthwhile to further explore.

2. Motivation/project objective

The focus & approach of the AE-Maas project

This project is based on the emerging concept of Mobility as a Service (MaaS), which has been growing in interest in recent years. MaaS (further described in the next section) refers to a flexible, personal, integrated transport service. The aim of MaaS is to meet the transport needs of a customer through an interface platform, which seamlessly integrates multiple modes. It is believed that such a system, often building off an existing public transport system, can address the shortcomings of public transport with respect to flexibility, efficiency, and comfort. The shared mobility aspect of MaaS, where mobility occurs collectively as opposed to individually, contributes to environmental sustainability by potentially reducing the number of private cars on the road network. Conventional public transport is inherently shared, and new forms of shared urban transport, including car sharing, carpooling, ride sharing, and bike sharing, are becoming more widespread. MaaS systems often aim to integrate current public transport systems with these newer shared mobility services. Integrated effectively and implemented correctly, MaaS has the potential to encourage a mode shift away from private vehicle usage. Interest in MaaS has increased due to nearly ubiquitous smartphone usage that allows for the development of apps to manage mobility, as well as the trend of sharing economies that focus on usage, not ownership.
With MaaS as the base of this project, and given a focus on improving the environmental sustainability of urban mobility, it is logical to consider how electric vehicles can be incorporated into a MaaS system (thus E-MaaS). Given the integration with existing public transport, supporting the integration of electric buses into the traditional public transport system is one potential

component. Additionally, further advancements of the concept of MaaS focus on the first and last mile of journeys. There are numerous options for the first and last mile legs of a journey within a MaaS system, but this project gives special consideration to motorized modes, with a focus on electric vehicles. While the use of electric vehicles has been increasing, there is still a need to accelerate preparations for a large-scale transition in urban electric mobility in order to meet the goals for sustainable development and management of cities.

Continuing to build on E-MaaS, the integration of autonomous vehicles into a MaaS system (thus AE-MaaS) could potentially further improve the service level of urban mobility systems. Using autonomous vehicles in the first/last mile of the MaaS trip removes the need for a driver and can allow for greater flexibility and comfort in travel for customers, increases vehicle utilization rates, and provides the ability to easily optimize and redistribute vehicles around the service area (Pavone, 2016).

As described above, and seen in Figure 1, the concepts of MaaS, E-MaaS, and AE-MaaS build on one another. A functional MaaS system in crucial before components of electric and autonomous mobility can be layered onto the system. However, at the same time, it is important to understand how electric and autonomous mobility can be built into a MaaS system successfully.

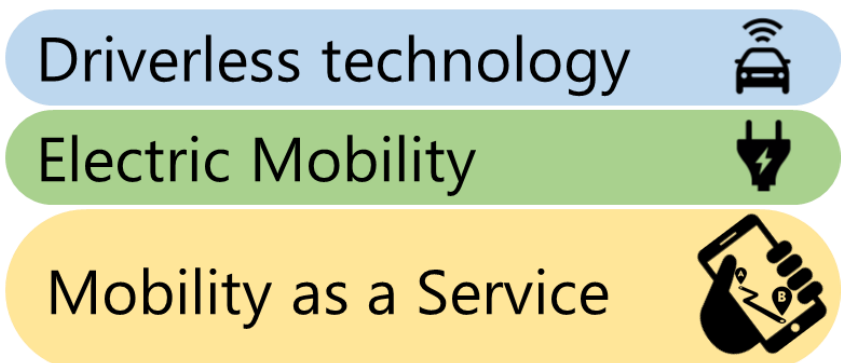

Figure 1 - The layers representation of the AE-MaaS project

This project examines the idea of an AE-MaaS system at a city scale to understand the benefits and challenges in implementing such a system. There is a specific focus on examining the environmental sustainability impacts of such a system. This work aims to understand the feasibility of an AE-MaaS system, identify critical elements of AE-MaaS development, and understand to ensure that sustainability is reached when developing AE-MaaS systems. Knowledge gained in this project can be utilized in the development of demonstration projects to test AE-MaaS as an urban mobility solution. At the systemic level, a MaaS/ E-MaaS system would streamline the current public transport infrastructure. Adding an autonomous element to a MaaS system then allows for more efficient transport routing and less congestion, improves road safety, and increases mobility for those with mobility challenges, such as the elderly.

Three different perspectives were considered within the project: Cities and Citizens, Vehicle & MaaS Technology, and Context and Economics. These perspectives address the numerous facets of AE-MaaS to be considered:

- Cities and Citizens: cities as a system, needs of different target groups, elaboration of different user cases, changes in user behavior, mobility aspects of current transport nodes
- Vehicle and MaaS technology: autonomous driving, light-weight but safe construction, materials and circularity, battery and charging technology, big data, ICT
- Context and Economic feasibility: legislation, ethics, preconditions, standardization, value chains, business cases and business models

These perspectives can also be connected with the Quadruple Helix approach which considers the interaction between four main actors as a way to foster innovation. As seen in Figure 2, the quadruple helix model suggests that collaboration of industry, academia/research, government, and users/civil society accelerates the transfer of knowledge, research, and innovation into practice and policy (Arnkil, Järvensivu, Koski, & Piirainen, 2010).

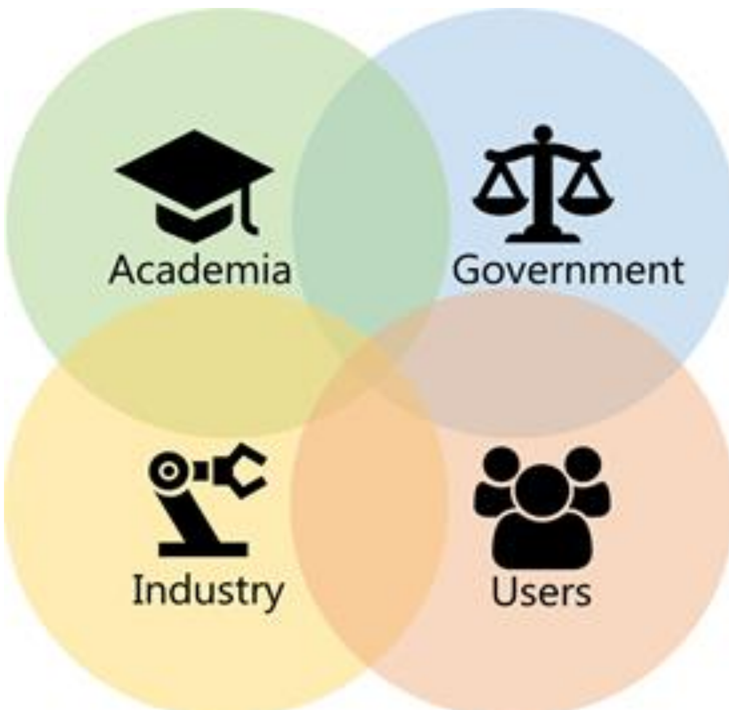

Figure 2 - The Quadruple Helix approach scheme

Within this project and the associated consortium, three of the four actors within the Quadruple Helix are represented, as seen in Table 1. Only one group, "users", is not represented within the consortium, but the needs of users are considered within the project through the previously mentioned perspectives. User perspectives were also taken into account in a survey with users in a trial of a self-driving bus in Helsingborg, Sweden, which was performed as part of the project, as well as a survey of existing commuting habits at a potential demonstration location (both located in Section 5).

Table 1 - Consortium composition and role

Partner	Contact Name	Quadruple Helix	Perspective
NTNU Norwegian University of Science and Technology	Kelly Pitera Giuseppe Marinelli Judith Borsboom-van Beurden	Academia / Research	Cities & Citizens Context & Economics
Trondheim Municipality	Bjørn Ove Berthelsen	Government	Cities & Citizens
Vejle Municipality	Boris Schønfeldt	Government	Cities & Citizens
Sør-Trøndelag County	Janne Lønsethagen	Government	Cities & Citizens Context & Economics
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FourC	Tor Rune Skoglund Sigmund Henningsen	Industry	Vehicle & Technologies
Mattersoft Ltd	Mika Varjola	Industry	Vehicle & Technologies
ecar – A Europcar Company	Russel Fenner	Industry	Context & Economics Vehicle & Technologies
SINTEF	Jon Are Suul Hans Westerheim	Academia / Research	Context & Economics Vehicle & Technologies

3. State of the Art

What is MaaS?

Within our consortium, as well as within literature, there are many different ways to define Mobility as a Service (MaaS). Perhaps the broadest definition of MaaS is "buying mobility services based on consumer needs instead of buying the means of transport" (Kamargianni, Li, Matyas, & Schäfer, 2016). This definition provides the core vision of MaaS without imposing restraints on what a specific MaaS design could be. Nevertheless, identifying some common characteristics that should be present in a MaaS could be helpful in order to distinguish between advanced MaaS schemes and other, less integrated services (read: Uber, Lyft, collective transport apps, etc.). In order to be seamless, the service should provide ticket and payment integration (ie. one ticket and payment solution for the various modes of a multimodal trip), mobility packages providing the opportunity to pay for a predefined amount of travel using a combinations of modes, and ICT integration (Kamargianni et al., 2016). Jittrapirom et al. (2017) offers a similar, though more detailed list of "core characteristics" that emphasizes many of the same aspects, specifying that there should be a single platform (app or web page) and demand-orientation.

A different approach to defining MaaS is a hierarchical one, which shows how a MaaS scheme builds on existing innovations in personal transport services. Holmberg, Collado, Sarasini, and

Williander (2016) provides such a model for identifying "levels of MaaS", ranging from car pool and peer transport services on the lower end to advanced MaaS schemes on the other end of the range. In this model the definitions of MaaS presented above would fall under the term "Combined Mobility Services", or "Integrated Public Transport", depending on whether the service provider is a neutral third party or the public transport operator.

MaaS could be considered as a collective of different stakeholders, where the MaaS operator/mobility broker is the facilitator of seamless interaction between transport, ICT providers, and end-users (Holmberg et al., 2016; König, Eckhardt, Aapaoja, Sochor, & Karlsson, 2016). The broker's role is to handle ticketing and payment, provide real-time information and route (including mode) planning for the end-user for the whole trip from A to B, and procure transport services from the different providers, such as public transport, ridesharing and bike rental.

Within this project, we consider a broad definition of Mobility as a Service in order to avoid prematurely limiting the scope of exploration. As mentioned previously, **we define MaaS as a systems-oriented approach of integration of numerous transport services into a single, seamless mobility service using a technology platform**. Note that while MaaS has often been described as an answer to the challenges of predicted increase of urban transport (J. Sochor, Karlsson, & Strömberg, 2016), this definition does not implicitly include goals of sustainability or other societal benefits. While MaaS has the *potential* to be an important tool to decrease use of private vehicles and increase the use of public transport, these impacts cannot be taken for granted. Therefore, efforts should be directed towards ensuring that the MaaS scheme is designed in such a way that it is efficient and sustainable, including resulting in reduced total vehicle-km traveled and increased demand for environment friendly modes.

Existing MaaS Systems & Projects

Existing MaaS projects or systems are identified and compiled in numerous sources, including Goodall, Fishman, Bornstein, and Bonthron (2017), Jittrapirom et al. (2017), Kamargianni et al. (2016), König et al. (2016), and MaaS Alliance[1]. Over 30 systems can be identified and many system are similar in nature. Information about five relevant MaaS systems shown in Table 2 with two described in more detail.

1 https://maas-alliance.eu/

Table 2 - Existing MaaS projects/services

	Whim	UbiGo	Qixxit	Entur	TransitApp
Location	Helsinki, Finland	Gothenburg, Sweden	Germany	Norway	USA, UK, Canada, Europe, Australia
App	✓	✓	✓	✓	✓
Payment: sub	✓	✓			
Payment: ticket	✓		Redirects	✓	✓
Trip planning service	✓		✓	✓	✓
Real-time info			✓	✓	✓
Ownership	Private	Private	Public	Public	Private
Incorporated Modes					
Airplane			✓		
Train	✓	✓	✓	✓	✓
Bus	✓	✓	✓	✓	✓
Car sharing	Will be added.	✓	✓		✓
Public bike	Will be added.	✓	✓		✓
Bike rental					✓
Ridesharing	Will be added.		✓		✓
Taxi	✓	✓	✓		✓
Car rental	✓	✓	✓		✓
Autonomous vehicles					

Whim[2] bills itself as the world first MaaS operator, originating in Helsinki. The service currently combines public transport (regional buses, commuter trains, trams, metro and ferries), two taxi companies and rental cars, with plans to adding new services, like city bikes, long-distance travel and car sharing services in the near future. Whim is a product/service of MaaS Global, a third-party provider in the transport market. Whim aims to grow their company outside of Helsinki, with

2 http://whimapp.com/, http://maas.global/

current plans to expand into the UK, and beyond. Given that Whim is a private company, there is limited information on the operation or usership of the service.
Another project of interest is UbiGo[3], a project which was developed and tested as part the project Go:smart, which considers innovative and sustainable urban transport solutions. The focus of the project was on the viability of the business model, which also considered the user's choices regarding sustainable transport modes. The six-month field operational test in Gothenburg, Sweden involved 195 participants who tested the UbiGo mobility service for everyday travel. Results of the study are presented in the following section.

Main research literature on MaaS

The majority of current research on MaaS attempts to analyze the possibilities, conditions and implications of MaaS. The research focuses both on which elements are necessary to make up a complete MaaS scheme, but also the different stakeholders' needs in order to ensure that the service will be economically viable and attractive to the user.

The main challenge is to design the MaaS scheme so that it is both economically viable and provides an attractive service for the end-users, while also fulfilling goals of reduced private car use – assuming that is a goal of the service (J. Sochor, Strömberg, & Karlsson, 2015). For a MaaS scheme that aims to reduce the use of private car and increase the use of public transport, it is suggested that the public transport actor needs to be the main transport provider in the MaaS system (Holmberg et al., 2016), regardless of whether the mobility broker is a third-party or the public transport actor itself.

In order for the MaaS system to function economically, both the mobility broker and the transport providers need to make a profit while the customer does not experience such a rise in prices that they choose not to buy the MaaS service. One example of how to achieve this is the UbiGo field operational trial, as described by J. Sochor et al. (2016); (2015; 2014) and (Holmberg et al., 2016). The UbiGo service successfully moved transport demand away from the privately owned car. The service was based on an app where the participant households bought a certain amount of credits at the beginning of the month, and could use this to access public transport, carpool, taxi, rental cars and public bikes. The added value of seamlessness and "the transportation smorgasbord" of the MaaS app increased the willingness to pay (J. L. Sochor et al., 2014), and since the service was pre-paid, the mobility broker became a large customer of the transport providers and could get lower prices per trip.

However, due to the Swedish subsidies of public transport, UbiGo could not make a profit from the PT trips, which made up the majority of the travel. Therefore a shift to public transport over the other services resulted in lower profits for the mobility broker. Another issue was that while the transport providers gained customers they lost brand exposure as sub-contractors to UbiGo. (J. Sochor et al., 2015).

Some additional challenges and barriers are identified in the literature. These include designing a service that is competitive with the private car (Holmberg et al., 2016; Lund, 2016), specifically ensuring user costs are lower than the value created by MaaS, and those of owning and driving the personal vehicle. Another challenge is the question of whether the public transport provider or a third party should run the mobility broker: Holmberg et al. (2016) argues for the latter, but this might conflict with a city's subsidization of the public transport system and require changes in

3 http://ubigo.se/

legislation (Li & Voege, 2017). Avoiding conflict between the different transport providers (Jittrapirom et al., 2017) is also crucial. The business ecosystem of MaaS may require changes in the individual business models of these transport providers, and they must be willing to open data to a third-party, allow this third-party to sell their service and offer electronic payment and ticketing (Li & Voege, 2017). Mature ICT technology and sufficient computer power in time periods of high transport demand is also crucial (Kamargianni, Matyas, Li, & Schäfer, 2015).

4. The sustainability of the AE-MaaS system

A MaaS system, even if not based on autonomous mobility and/or electric vehicles, has the potential to drive towards a more sustainable transportation model in urban (and likely rural) areas. The sustainability benefits, as well as potential adverse impacts, were discussed by the consortium in a workshop setting.

Environmental impact of MaaS

Numerous sustainability effects that MaaS (with or without autonomous vehicles) can induce into the transportation system were identified. These include:

1. Increase in shared mobility
2. Decreased congestion
3. Reduction for the need of space for traffic
4. Decrease in private owned vehicles / replacement of the first car

A MaaS system provides the possibility to increase the occupancy of each vehicle, and the acceptance of a **shared mobility** system by the users represents a relevant step forward towards the reduction of GHG gas emissions and fuel consumption. A higher occupancy will reduce the total number of vehicles traveling on the road network, ignoring the potential impacts of latent demand. Shared mobility also has the connected effect to potentially **reduce the traffic congestion** due to a reduction of the number of circulating vehicles. Reduced congestion is also a consequence of an intelligent routing system that can be able to optimize the route for each shared vehicles (whether this is autonomous or human driven), increasing efficiency and avoiding congestion as much as possible. The reduction in vehicles and reduced congestion, makes it possible to **reduce the space dedicated to traffic**, especially in urban areas where there are large collectors roads with high capacity (numerous lanes). It could be possible to reduce the road surface and substitute it with denser urban planning or green areas. The latter could increase air quality and encourage people to spend more time outside or walk/run/cycle more, with a general benefit for health as well.

On common goal of MaaS system implementation is a **decrease in privately owned vehicle**s. If users of the MaaS system have their mobility needs met by the system, they might rethink their need for personal vehicles. Additionally, it is not unusual for a family to own two cars (especially in Nordic regions), one for daily urban mobility and one for longer journeys or weekend trips. Generally the first car is the one that drives the most mileage and since MaaS has to potential to operate in fully urban environment, it can potentially **replace the first cars**, although people are likely to still own a second car for leisure trips.

As well as benefits, some possible side effects can be obtained if the MaaS project is not planned accurately. These adverse impacts are relevant regardless of whether AVs are included within the MaaS system. They can be summarized as:

1. Increase of traffic
2. Excess in motorization of the first/last mile trips
3. Induction of new transport needs
4. Competition with public transport
5. Environmental sustainability of the vehicle fleet

If the sharing concept of MaaS is not incentivized enough with, for example, a smart pricing strategy, users could be encouraged to use personal motorized vehicles within the MaaS system for trips which were previously done with public transport or non-motorized modes, mainly for comfort and travel-time reasons. This can induce an **increase in the traffic on the transportation network**, and also a possible **shifting from first/last mile trips which previously occurred by cycling, walking or other environmentally friendly ways**. This last point highlights clearly the issue of attracting the "right" customers to the service: the system should aim to attract car drivers instead of cyclists, pedestrians, runners, etc…, and not **induce new transport needs**.

Furthermore, the system should cooperate synergically with the existing transport system, avoiding conflict or **competition**. This means that the MaaS system should avoid proposing or allowing trip alternatives that overlap with the public transport system (potentially offering this option only to specific categories of users or in case of specific users' requests/needs), or at least price such trips higher.

Another side effect, related to the **vehicles** involved in the system, whether they are electric or autonomous, is their **environmental impact** along their lifetime, from production to demolition. Considering the sustainability of the system, it is necessary to include and evaluate the sustainability of the vehicles of the fleet, since they represent a component of the system itself. Key aspects here include materials used to manufacture the vehicles, as well as battery production and disposal. This effect is not likely to be too great, compared with the environmental impact of the current vehicle fleet.

Environmental impact of electric vehicles within a MaaS system

Electric vehicles have the potential to have an incredible impact on sustainability of the transport system by their own, due to many reasons connected to their engines, their emissions, and their maintenance. When electric vehicles are inserted inside a MaaS system, the sustainability effect of such a technology is enhanced by the scale effect. From a locational perspective, the insertion of electric vehicles inside a MaaS system can generate a pollution reduction that is spread in a wide area, instead of the specific location where EVs are deployed. Aiming to electrification of the whole MaaS system can bring to a better air quality in a wider geographical area.

These impacts are specific regarding the insertion of electric vehicles into a MaaS approach. Numerous other sustainability advantages are available from EVs in general, but for those please refer to existing literature in electric mobility.

Environmental impact of autonomous technologies within a MaaS system

It is widely accepted that AV technology will have a major effect on traffic safety, since nearly 90% of vehicles accidents are due to human factors. Additionally, AVs can also have a significant environmefrntal impact on the transport sector, acting in many different ways. In fact, it is believed that AVs have the potential to both increase or decrease the GHG emissions and fuel consumption from the transport sector, depending on which of their specific effects have larger uptakes in future applications. Some of the major effects that AVs will have on the society can be summarized as follows (Brown, Gonder, & Repac, 2014; Wadud, MacKenzie, & Leiby, 2016):

1. Platooning
2. Efficient Driving
3. Efficient Routing
4. Travel for underserved population
5. Faster Travel
6. More Travel
7. De-emphasized vehicles' performances
8. Higher occupancy
9. Urban sprawl

The term **platooning** refers to the practice of numerous vehicles driving one behind another closely. This practice (whether it is performed by human drivers or, more recently, by autonomous vehicles (European Truck Platooning Challenge, 2016) can lead to reductions in aerodynamic drag for all of the vehicles, but particularly for the vehicles in the middle of the pack. Although this practice could be performed also by human drivers, it is highly likely that the major benefits will be achieved through autonomous driving technologies, since they can drive at higher speeds and with closer spacing, compared to humans. Wadud et al. (2016) estimated that this practice (if performed with AVs) could generate energy savings up to 25% for both LDVs and HDVs (Light Duty vehicles and High Duty vehicles). Although, considering how autonomous vehicles will be utilized within an AE-MaaS system, it is not likely to see such energy savings.

More **efficient driving** is expected through a set of driving behaviors that can lead to energy savings while driving, such as smoother starts and stops, lower accelerations, constant speeds (also named "ecodriving"). Since AVs could have the potential to operate with a smoother driving style, it has been estimated this efficiency could lead to a reduction in energy intensity of up to 15%. At the same time, the improved driving abilities of AVs can result in reduction, or even removal, of safety countermeasures that are now in place for human drivers. This could lead to a general **increase in travel speeds** and increased speed limits, leading to up to a 30% increase in energy demand.

The ability to perform **smart and green routing** can lead to energy savings by, for example, avoiding traffic, using shorter but modestly slower routes, and selecting routes with fewer stops. Smart routing is estimated to provide up to 10% of energy reduction also considering the overall benefit from the overall **improved traffic flow**.

AVs could also **induce new classes of traditionally underserved passengers onboard**, like young, disabled or elderly people. This effect can be counterproductive from an energy standpoint and lead to an increase in energy demand and emissions. It has been estimated that this effect could induce a growth in travel from 5% to 40% in the long term. Additionally, the comfort of travelling with such vehicles could **induce even more travels** among people already using the car currently (can be estimated up to 50%). On the other end, improved comfort onboard and less safety needs could lead to lighter vehicles with **de-emphasized performances**, leading to less energy consumption and less speed.

Within an AE-MaaS system, users could have to opportunity to choose to share AVs, perhaps in exchange at a lower cost, thus **increasing the occupancy** of vehicles. There is uncertainty to what degree sharing will occur but it is estimated that this could result in a 12% reduction in use intensity.

From a planning perspective, a more efficient and flexible transport service may encourage **urban sprawl,** by making door to door mobility more comfortable and allowing for users to spend commute time to do things other than driving due to the autonomous vehicles. But given that MaaS intends to replace the use of personal vehicles, which also greatly contribute to urban sprawl, the effect is potentially negligible.

5. Demonstrations and projects

During this Pathfinder project, several scope-adjacent demonstrations or projects took place. This includes an autonomous electric bus demonstration in Helsingborg, Sweden, the start-up of a shared taxi project in Trondheim, Norway, a survey of travel habits of commuters in a business park area in Trondheim, Norway, and a summer school workshop. These projects, described below, can provide insights to the development of an AE-MaaS system.

The AE-bus experience in Helsingborg - Sweden

An autonomous bus ran between central station Knutpunkten in Helsingborg and a nearby campus area for a trial on September 16-20, 2017. The initiative to run the pilot came from bus operator Nobina and the city of Helsingborg. The electric-powered bus, which takes twelve passengers, six seated and six standing, ran without driver as part of a pilot study. Car traffic was suspended on the route during the execution of the test. Onboard the bus was a host from operator Nobina answering questions about the bus and the technology behind the vehicle. The bus has a maximum speed of 40 km/h, but during the pilot it never surpassed 20 km/h. It follows a digital map with fixed points and also uses GPS. The bus needed to adjust the speed to the speed bumps on the route. Interest from the public was large and a total of 1703 persons tried the bus during the five days of the pilot study.

As part of this project, Trivector conducted a survey on-the-spot with users. In total, 295 respondents answered a questionnaire. The vast majority (90%) of the passengers experienced the trip as safe, despite the absence of a driver (but with a host on board). A majority (80%) stated that they would have travelled with the bus even if a host had not been present.

People of all ages and both genders chose to try out the bus. All age groups felt safe traveling on the bus, except for a handful of people in the oldest age category, over 65 years old.

The respondents indicated that they see the biggest use of such a bus in bad weather, as connection to other public transport, and when you have a lot to carry. A small percentage, 3%, of travelers, state that they would never have use for an autonomous bus.

In general, respondents were positive towards autonomous buses and the majority would have used the service often or always had it been permanent. Most of the travelers believed autonomous buses would be a common sight sometime between 2020 and 2027. The majority (60%) of the youngest age-group, i.e. up to 17 years, believed it would happen within five years. Men generally believed in faster development than did women. Many described the autonomous bus as a good complement to other public traffic, and as an appropriate means of transport in the city where there is often a lack of space. Autonomous indoor buses, in areas such as large shopping centers, were also suggested as one possible area of use.

As all respondents had chosen themselves to test the service, the respondents may be more positive towards new technology and autonomous buses than the general population. Hence, this study does not provide the whole picture, but is an indication of acceptance of autonomous buses and in which contexts they may serve a need. The study indicated that the technology is there, that people are willing to use the service, and that users identify needs that autonomous buses could respond to. The question is whether the legal acceptance, which is now lagging behind, will be able to catch up with technology development.

The Taxi MaaS test in Trondheim, Norway

Sør-Trøndelag County has an ongoing project, Smart Transport, to initiate the first steps towards Mobility as a Service offerings, with a goal by 2020 to provide a mobility service solution through an app (or similar) containing at least two different modes of transport, for example public transport and taxi, with all features including payment and anonymous travel patterns through the app. A fully developed and operational MaaS system is intended by 2023.

Preliminary work has recommended that development of a MaaS system start gradually, with progressive introductions and improvements. The first (current) stage is a test of a solution for a joint taxi platform. This includes common customer information and taxi ordering through an app where is it possible to book and pay for taxis from any of the available taxi companies in Trondheim. The six month pilot (beginning in early 2018) is intended to provide a useful experience in dealing with mobility as a service through offering a new mobility product, coordinated taxi offerings, which can be characterized as in between current public transport and private cars. It will provide experience with customer perspective for the services. Customers will be surveyed and/or part of focus groups to gain insight into perceptions and preferences regarding the new scheme and travel habits. The potential for taxi sharing will also be explored, to better understand customers' willingness or reservations for sharing mobility. In addition to contributing to the development of MaaS, the pilot will give customers an overview of the taxi market, which today is difficult to access. Customer will get an overview of price, status, and quality for the different taxis, thus improving current mobility offerings.

It is believed that if mobility as a service is made successfully available in Trondheim/Trøndelag, there would be a reduction in dependence on private cars, thus helping to reach climate goals, zero growth target, and also see public savings through better custom public transportation offerings utilizing multimodal connections.

Travel habits and travel opportunities for commuters in Trondheim, Norway

A recent study surveyed over 1000 people who work within the Sluppen area of Trondheim on their commuting travel habits (Zhupanova & Tørset, 2017). Sluppen is a large business park with approximately 50 businesses and over 2000 employees. While there is currently ample parking available, as the area continues to be developed in the future, parking will be reduced. The business park owner is interested providing environmentally friendly transport solutions for its tenants, which will make it more attractive for employees to choose an alternative mode to private car for commuting (thus the motivation for the survey).

Key results from the survey include:

- 60% of respondents most often drive to work, 24% cycle (fewer in the winter), 9% use public transport, and 6% walk.
- Travel time by car to Sluppen for residents of Trondheim municipality is on average 12 minutes, 65% of those driving a car live at a distance of 10 kilometers or less from work.
- Main reasons stated for driving a car to the job: faster travel time, practical, and easy.
- 79% of respondents have parking available at the workplace. 7% pay the parking fee themselves, while the rest have access to free or subsidized parking. Among those who have free parking, 62% who choose to drive to work, while among those who pay themselves, only 38% drive to work.
- 37% of respondents have direct bus service from home to work, while 57% report that they do not have such an offering. The proportion of travel by public transport is much higher among those who have direct bus service (18%) than among those who do not (5%). Average travel time for public transport work for residents in Trondheim is 28 minutes for those who have, and 42 minutes for those who do not have, direct bus service.
- Average walking time from housing to bus stop is 5 minutes (for those living in the municipality, up to 40 minutes for those living outside of the municipality), while walking time from bus stop to the workplace is approx. 8 minutes.
- Stated measures would contribute to the more frequent use of public transport: direct bus service (54%), shorter travel time (39%), and more bus departures (32%). Respondents expressed strong reluctance towards a transition to public transport, mainly due to much longer travel time than by car.

The scene illustrated within the results of this survey is one where personal car is the preferred transport mode due to time and flexibility concerns, and lack of disincentives to drive. While this survey was not conducted as part of the AE-MaaS project (but instead as an independent project at NTNU), the results indicate that the Sluppen area could be a location of interest in demonstrating the potential for an AE-MaaS system to impact travel behavior.

The Journey

The Journey was a 4-week summer school, sponsored by Climate KIC, which offered 38 students from around the world the opportunity to "learn how to combine science and entrepreneurship to find solutions to climate change." The students spent two weeks of the summer school at the Norwegian University of Science and Technology in Trondheim. Several members of the AE-MaaS consortium offered a 1-day workshop on Sustainable Business Models. Students were asked to work in groups to consider the following questions:

1. Why should we build a sustainable business model for urban mobility as a service?
2. How should it be organized to set the business model apart from competitors?
3. What should be the product and service provided?

Key takeaways are summarized in the attached workshop documents.

6. Hypothesized Scenarios & Components

The consortium decided upon two different possible scenarios for incorporating AE-vehicles into a MaaS system. While these are not the only possible scenarios of AE-MaaS, they are perhaps the most likely. These scenarios were then evaluated considering the different perspectives and different components of each scenario, described further below.

The first scenario (Scenario #1) takes into account a fixed route autonomous-electric collective system which serves a given area, fulfilling the specific needs of that area. The service runs on one or several fixed routes and schedules determined Maas provider (which may be a public authority, private company, single person business, etc.). Thus, customers will not be able to demand a fully customized transport service but instead is subject to the fixed route service. It should be possible to access information about the service and order a seat on service via an IT platform. The service will run within a specified geographical boundary and with a specific objective. Examples of objectives include: a service which provides the first and last mile transport between a collective transport hub and an employment hub, a feeder service which connects a residential area to a larger collective transport network, and a shuttle that services a campus or several campuses. Given the nature of the service, there will be an element of collectivity within the autonomous transport element of the service. Vehicles will need to be sized for groups of customers, as opposed to individuals. For example, vans or minibuses may be the most appropriate. Smaller collective vehicles are also favorable for locations where the road network is not necessarily dimensioned for larger collective vehicles.

The second scenario (Scenario #2) considers an on-demand system with no fixed routes/schedule that allows users to choose their origin and destination, with the intention of complementing the existing public transport system. In this scenario the autonomous transport service is a based on a demand-request mechanism. Through a specific IT platform (mobile app, website, others) the user can ask for a customized “transport mission”, in which customer typically can define (at least) the origin, the destination and a timing. It may be possible to define other elements such as whether you travel alone or collectively, what type/size of vehicle is used, etc… There is no theoretical limit to the flexibility of the system in terms of space and time, although there might be a specific area in which the autonomous transport service can operate (a specific neighborhood, a municipality, a county, a nation). Assuming an intent to complement and connect with the existing public transport system, origins, destinations, or trip length could be limited in a way to require integration with the public transport and “soft-mode” transport networks. If it is not integrated, the autonomous transport service is actually an alternative separate transport option from the already existing ones, not working synergically with others options.

Figure 3 illustrates the two scenarios.

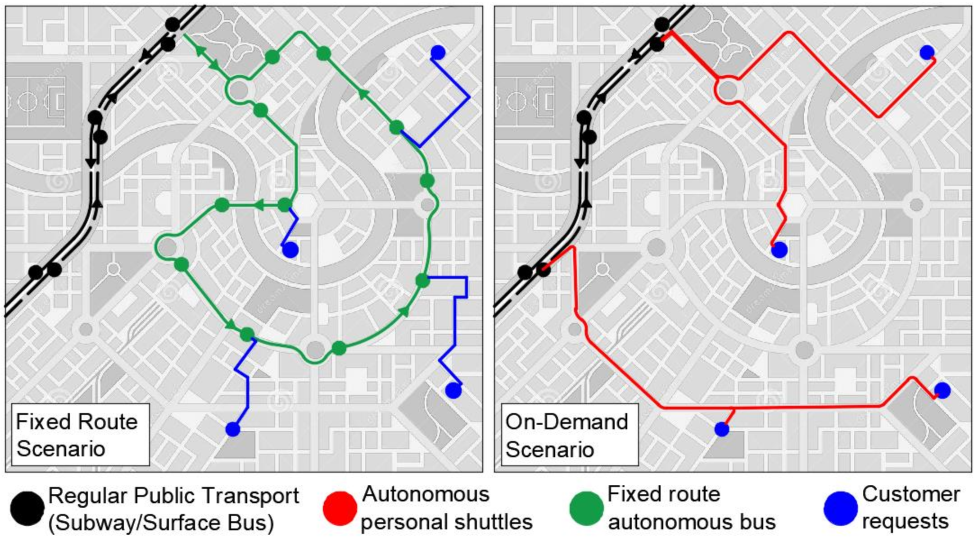

Figure 3 – Scenarios schemes

Within both scenarios, the autonomous vehicles could perform at different levels of automation. The standard for defining levels of automation is shown in Figure 4, where from level 3 upwards, the responsibility for monitoring the driving environment is the responsibility of the autonomous system. Level 3 though still requires that a driver be ready to take control of the vehicle. Most vehicle manufacturers are inclined to skip level 3 automation because of a lack of trust in human ability to take over control of the car as necessary in an emergency situation. Thus it is assumed that fully operational AE-MaaS systems will operate at SAE level 4 or 5. It may be possible to demonstrate an AE-MaaS system at SAE level 3 for a fixed route system with a larger vehicle, but for an on-demand system, this may be impractical, as users of the system would then also need to be licenses to drive AVs.

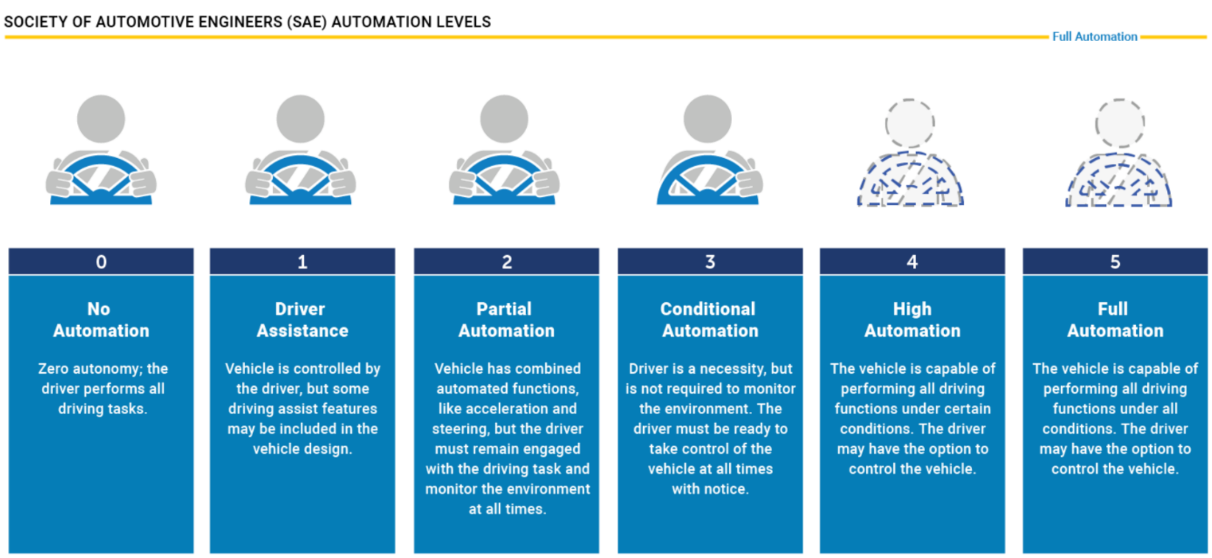

Figure 4 - SAE Automation Levels (NHTSA)

Each one of the two previous scenarios have been then evaluated with respect to seven components identified as key to a functioning, sustainable AE-MaaS system:

1. Vehicle
2. Technology Platform & Data
3. Users
4. Transport Model
5. Authorities/Transport Providers
6. Business Model
7. Sustainability Model

Considering specifically each perspective, groups (tracks) in the consortium have been asked to illustrate how the components affect each scenario. The tracks were identified in chapter 2 as Cities and Citizens, Context and Economics, and Vehicles and MaaS Technologies. The focus has been set on:

1. what are the specific issues that each components generate;
2. to identify the benefits/challenges and the unknowns which need to be addressed to create a successful AE-MaaS system;
3. identify any known existing resources we can use to address the benefits/challenges/ unknowns;
4. Suggest for further study to address or learn more about the benefits, the challenges and/or the unknowns.

It is noted that not all components are equally relevant for each track and that often there is not a clear distinction between the impacts of the two different scenarios. At the same time, there is overlap between the issues of interest and concern for the different tracks.

Scenario #1: Fixed Route

Cities and Citizens

From the Cities & Citizens perspective, the difference between the two scenarios is quite small. For that reason, in this section, emphasis will be on describing the features of the fixed route scenario, while we elaborate the on-demand last-mile scenario only when there is a considerable difference with the fixed route scenario.

Other factors, such as lifestyle and value orientations, factors influencing the need for mobility such as densification and spatial layout, urban planning policy and legislative framework are also very important. These factors have been addresses under the components “users” and “authorities/transport providers”.

Concerning **vehicle** technology, an important benefit for both scenarios is that electric vehicles contribute to the sustainability goals of both cities and citizens (no pollution, noise, CO2 emission, other use of public space than parking). This occurs, for example when citizens replace their traditional fossil fuel car with electric mobility as a service.

However, specific challenges on autonomous vehicle technology need to be solved for such a scenario to really take off. For example, is the autonomous vehicle safe in traffic? What are the liability issues in case of accidents related to the car or road and ICT infrastructure? Can the vehicles be hacked easily? What is the user-friendliness of operation of the vehicle by users?

How do the batteries perform in a Nordic climate? What is the sustainability of battery production during its life cycle, and how can it be improved (for example scarcity of raw materials, environmental pollution during production)? How to ensure seamless integration of vehicles with public transport to ensure acceptable mobility service levels? Which adjustments of road infrastructure are needed for autonomous electric vehicles? What is the impact on the electricity grid of large-scale deployment of electric vehicles?

With respect to the component **technology platform & data,** other benefits emerge. Foremost, the transport offer can be tailored towards specific user needs through ICT (e.g. transport suggestions based on previous behavior or different types of vehicles for different purposes). Further, the presence of a central technology platform and data on location of stops, real-time positioning, etc., enable a seamless integration with public transport.

However, there are challenges associated with the technology platform and data as well. Many AE-MaaS would rely heavily on personal data, which might fall under legislation around data privacy. In Europe, new legislation on General Data Protection Regulation (GDPR) will come into effect per May 2018. In addition, the ownership of data might not yet be clear. In addition to hackability of the vehicles, there is also a concern of hackability of the systems. What is more, the easiness of operation of the platform for users will determine its acceptance by users, but might raise questions on inclusiveness of ICT-illiterate people. As the technology platform connects to ICT and physical infrastructures, wide-scale deployment will probably raise many issues regarding interoperability, Internet-of-Everything and standardization.

With respect to **users, life-styles and value orientations** AE-MaaS can provide a great deal of benefits. It offers an easy mobility solution, and users do not have worries about hidden costs of private transport and maintenance etc. Public transport users may enjoy higher levels of accessibility, and subsequent substitution of private car transport by AE-MaaS may lead to less congestion on roads. Finally, users of transport can endorse a sustainable life-style in this way.

Specific test cases provide more information on Mobility as a Service. The GoSmart and SendSmart projects in Gothenburg have demonstrated shifts in modal choice and less private car mobility resulting from a good offer of other transport options and an easy user interface. The reports of the Vejle Municipality (Section 8) and Helsingborg (Section 5) pilots light on what is needed for safe and secure operation, and acceptance of autonomous driving and transport (Helsingborg) and how this new technology can enhance a better city life and be integrated in a city's overall ambitions (Vejle).

However, it can be expected that AE-MaaS will disrupt existing value chains and bring about new models of ownership and business. This will influence social acceptance of large-scale deployment of such systems. Essentially this might be the same discussions as with every transport issue: which trajectories are chosen, who has the benefits, who has the disadvantages e.g. parking facilities or the fixed route bordering his/her house. The easiness of operation and cost of use of AE-MaaS for users will determine its acceptance. Nevertheless, it might raise questions on inclusiveness regarding ICT-illiterate people and specific population groups such as the elderly. See, for example, the reporting of Trivector on the AE bus pilot in Helsingborg. As with the technology platform, data privacy issues will have to be solved. It is not clear if AE-MaaS will result in higher costs of transport for end users due to investments in the system, and if the service level will remain the same, or become better, for example in less dense areas.

At the moment, there have been pilots and testing of partial components, but it is unclear what an integrated, fully-fledged AE-Maas means for citizens and end users, also including local businesses, and what it will deliver to them in terms of performance. There is currently hardly any reliable information about the pace and degree of changes in travel and transport patterns and behavior which might be expected in these two scenarios. Further, many local governments do not have assumptions on the pace of market uptake and are not yet preparing policies Therefore outlooks and ex-ante impact assessments are needed.

For the component **transport model,** main benefits from the perspective of cities and citizens are its contribution to making the transport system more sustainable by less CO2 emission, and less air and noise pollution, because of full electrification of the urban transport system. In potential, AE-MaaS can also contribute to better accessibility (see component users, life-styles and value orientations) and less congestion due to more efficient use of road capacity with fewer vehicles.

Despite these advantages, there will be remain some challenges. Accessibility and service level of public transport will be determined by the choice of locations for stops and routes. It is also not fully clear to assess whether all current physical and digital infrastructures as roads, electricity grids, broadband/glass fiber networks are yet suited for wide-scale AE-Maas.

The component **authorities/transport providers**, which related to policies and regulation is highly relevant for cities and citizens during introduction of AE-MaaS. Governments and authorities at different scale levels might attain their sustainability goals while also safeguarding or even improving mobility and accessibility for their inhabitants. Less parking places will be needed in cities, and this will free up space for other purposes. And finally yet importantly, being a test site for AE-Maas contributes to a city’s branding and image, and can attract more investments by industry and financers. However, it is clear that in particular for government and authorities, many challenges can be expected in different fields. In the pilot phase, it is important to find local motivation to test and implement AE-Maas. New ownership structures of autonomous electric vehicles and related infrastructures can raise questions on responsibilities for public amenities such as safety, security, and accessibility, about liabilities, about allocation of maintenance costs and about public procurement. Who will bear the costs to update current physical and digital infrastructures, such as roads, electricity grids and broadband/glass fiber? Some citizens and local businesses might show not-in-my-backyard (NIMBY) reactions towards parking and routes, when these need to be embedded in the urban fabric. From the physical and transport planning perspective, important topics related to AE-MaaS are minimum densities required for collective and individual transport solutions, green field versus brown field urban expansion, and Transit Oriented Development (densification around nodes of public transport). Concerning electrification of the urban transport system, local governments and authorities need to deal with choosing the right location for a public charging infrastructure, its local impact on the dimensioning of the electricity grid, standardization issues and bi-directional exchange of energy with buildings, for example coming from positive energy blocks.

Specific unknowns for governments and authorities differ considerably during the testing phase and large-scale rollout of AE-MaaS. The case of Vejle shows that before agreeing on an autonomous driving pilot, the local government wanted to answer six specific questions on technology, location, city life, climate and environment, and citizen’s needs, in a self-assessment:

1. Why is this new technology particularly interesting to use?
2. How does this new technology enhance a better city life?

3. What is the purpose is of testing the autonomous vehicle, and is the chosen location really the best place, where the test can proof the purpose?
4. How can the autonomous buses enhance the livability of the city?
5. How do we innovate new solutions around the use of AV's that will exploit the new technology to lower the collective climate impact?
6. How do we secure that the testing will become a success for the end user, and do we aim at a defined group of people?

There are also several unknowns when preparing large-scale rollout. For example insight into the costs and benefits of citywide introduction of AE-MaaS systems. But also how to decide on the location and features of physical and digital infrastructures needed to support such an AE-MaaS system, and how to link it to policies and decisions on land use and real estate (re)development.

From the viewpoint of **business model,** the combination of autonomous driving, full-scale electrification and Mobility as a Service, can be highly disruptive for existing value chains. It will create new market opportunities for businesses in automotive and ICT, but will significantly disrupt the business model for current transport operators. As said earlier when the component authorities/transport providers was discussed, new ownership and license structures will appear. Important challenges will be the mitigation of risks, needed (pre) financing of investments, and a demand for specific instruments for successful PPP's in AE-MaaS and novel governance arrangements. However, as for local governments and authorities, it is yet hardly known how to implement AE-MaaS at city or region scale, and the volume of investments it would take.

Related to the **sustainability model**, clear benefits for sustainability are generated by the full-scale electrification of transport underlying AE-MaaS. It features lower external costs compared to fossil fuel-based private mobility, public transport and freight. Additionally, a successful AE-MaaS system will reduce personal car miles, replacing them in part with shared mobility miles. By creating new business opportunities and hi-tech start-ups, AE-MaaS can contribute not only to environmental but also to economic sustainability. An important challenge will be that sustainability gains are not clearly visible without extensive monitoring of relevant aspects of all physical components during their whole life cycle, for instance of batteries. Quantitative models should be applied to clarify the broad impact of AE-Maas on all aspects of sustainability, so people, planet and profit.

Specific to Cities and Citizens, but also considering the other tracks, the list below contains an overview of further study suggestions:

- What is needed for safe and secure operation and use of the vehicles?
- What should be the design principles for a bidirectional charging infrastructure in the built environment for vehicles?
- When do users trade in their fossil fuel cars for such a system, when do they find it attractive?
- How can we improve the sustainability of new batteries?
- What are exactly the sustainability gains in a broad ex-ante impact assessment, including safety and security, inclusiveness aspects? Can we monetarize them?
- How do we innovate new solutions around the use of AV's that will exploit the new technology to lower the collective climate impact? (Vejle)
- Is it only technology push?

- Transport end-user research on preparedness to change transport modes on components of AE-Maas systems
- Is AE-Maas suitable for everyone or only for young, highly educated people?
- Cultural and demographic aspects of transition towards AE-Maas, for instance related to age or (ethnic) background
- How can the autonomous buses enhance the livability of the city (Vejle)?
- What can we learn from demonstrators, e.g. on pace and degree of expected changes in travel and transport patterns and behavior, and on real performance of components of AE-Maas?
- What are the short and long-term aspects of transport and spatial planning that need to be changed to enable AE-Maas and more sustainability?
- What policies and strategies are needed when?
- Where the legislative and regulatory framework should be changed to enable AE-Maas, including competitiveness rules?
- How big is the market and at what pace will it unfold?
- Which parties are interested to finance this?

Context and Economics

Within both scenarios, under the track of Context and Economics, issues and concerns related to the business model, regulations, and the setting/location are considered.

In a fixed route scenario, the **vehicle** will need to be sized for larger numbers of customers, as opposed to individuals. For example, vans or minibuses may be the most appropriate type of vehicle. Because the vehicles utilizes a known route, it is easier to anticipate demand, schedule service, and organize charging, thus easier to determine the number of vehicles needed in a system. Considering authorization to operate autonomous vehicles, a fixed route scenario would use select a specific roads within the road network. This could perhaps ease authorization to use AVs as part of the MaaS system, especially in early phases of AV implementation.

For both scenarios, the **technology platform** is crucial to a MaaS system, as it should allow for payment of travel, and route planning using multiple modes and/or multiple transport providers (all 3 key elements of a MaaS system). Challenges include integration of booking systems from multiple providers, particularly in the commercial sector. This requires strong cooperation and agreement amongst partners. Data sharing will be required, thus it is important to understand the regulations and privacy concerns around such data transfer. It is also important to understand which data is necessary for operations (ie. location of services, booking, payment...) versus data that parties might like to have but do not need (such as detailed usage patterns of all user). The latter category of data is likely harder for private companies to justify sharing. Another challenge regarding data concerns the availability and consistency of data. There will be costs for buying data which is not openly available. We must also consider the compatibility across Europe with different public transport providers/approaches (for example, UK is different to much of mainland Europe). The ability to modulise the system to build in multiple providers rather than rebuild a new MaaS solution, would speed linking of services. The business model used and participating organizations will affect technology choices. The commercial benefits for transport providers of supporting such a system is unknown.

In a fixed route system, high levels of ridership are dependent on understanding the **users**. The routes need to meet the origin and destination demands of the users, and the service needs to provide an advantage over the user’s transport mode alternatives at a competitive price. Users’ view of automation and potential safety concerns are also relevant to ridership levels. Thus careful selection of service areas and potential customer groups in important to a successful system. A greater understanding of how access to such an AE-MaaS system would impact people's travel behavior is needed. Ultimately, for a fixed route service, a series of destinations with an existing or derived travel demand between destinations would need to be identified within a **transport model** to establish routings and vehicle needs.

Within a fixed-route system, **local authorities/transport providers** are knowledgeable about the local context. This include knowledge regarding where the routes should be place to complement (not compete) with existing public transport, and practicalities on who has authority over use of the road and feasibility of autonomous vehicle approval. Public authorities have an overarching view that users or private entities might not see, for example concerning urban mobility challenges, and can manage issues across transport modes. Public authorities also have the ability to influence, to varying degrees, mobility offerings and policies, thus can promote sustainable mobility.

It is assumed that MaaS will function as either a private initiative or a public-private partnership. For an AE-MaaS with a fixed route scenario perhaps lends itself better to a public-private partnership **business model**, as the autonomous portion of the system would operate similarly to a public transit route. Within such a business model, the public authorities can set guidelines and regulations to ensure the system meets the needs of the community, while the private entities have flexibility to optimize the system. Current public transport services are often subsidized, but new offerings through a MaaS system should increase the users, hopefully increasing the financial viability of public transport services. Aspects regarding pricing and profit must be considered. For example, should the service be priced as a package flat monthly fee, cost per use of each transport mode, or a blend of the two? How does each provider benefit from this? Is there enough value in the MaaS solution for it to be cost effective to produce and operate the software? Is there an administration fee on each booking or commission?

As stated above, the public authorities have the potential to set guidelines and regulations regarding the implementation of a MaaS system (although this is subject to the conditions for transport offerings and procurement in different countries). If **sustainability** is an important consideration within urban mobility, public authorities have the ability to shape aspects of a MaaS system to meet local sustainability goals. For both scenarios, can an environmentally sustainable system be also economically sustainable? The environmentally sustainable components of an AE-MaaS system consist of: (1) increased sustainability due to EV use, (2) increased sustainability due to AV use, and (3) increased sustainability due to shift from personal vehicles to shared/collective transport MaaS system offerings. The service must be based on an understanding of the components of a MaaS system which impact environmental sustainability if economic sustainability and environmental sustainability are to align. This is further discussed in chapters 4 and 8 of this report.

Vehicle and MaaS Technology

The vehicle and MaaS technologies track considers both the vehicle technology, as well as the information technology used to operate a MaaS platform.

The fixed route scenario with respect to the **vehicle** would be quite similar to “ordinary” time-table based public transport. It would mean that the number of passengers would be “known” to a certain degree, and it means that vehicle sizes needs to be scaled quite close to the number of expected passengers for that first/last mile.

If only one vehicle size was utilized, these vehicles would most likely be larger necessary for all journeys since one would serve large and small passenger loads from the public transport system. In this sense, it also ties up more resources in larger and more vehicles that usually necessary - since some vehicles obviously will have very little load at off-peak-hours of the day.

Several of current manufacturers of buses for public transport are delivering electrical buses today. Of the larger, European manufacturers on the market, these include Volvo, Mercedes-Benz, Solaris and Iveco, to mention a few. However, none of these have yet autonomous, electric buses as part of their standard offerings. Smaller companies have however demoed AE buses. These include companies like e.g. Olli, Ligier and Navya. Typically, these buses are smaller (more like larger cabs) and moves slower than “ordinary” buses.

Scenario #1 is the responsibility of public transport authorities in most parts of Europe as of today. With respect to **technology platforms and data**. Current technology platforms exist that handles most of the technology for public transport with the fixed route scenario, at least up to the autonomous level. Current platforms for this includes those based on the CEN Transmodel framework, with standards like NeTeX, SIRI and IFOPT, in addition to proprietary solutions. The project has not looked into which platforms that are needed for the autonomous part. It is assumed, though, that autonomous driving solutions for a vehicle are very much the intellectual property of the vehicle manufacturer.

Most **users** of a scenario #1 system would use the system in similar ways as they do in ordinary public transport systems of today, i.e. get to the bus stop, optionally change vehicle at stops and get off at the last stop, while expecting that the vehicle would be on route according to the time table - or be notified/informed about deviations. The major exception is that users will not be able to ask the driver for help, ticket purchases or other matters. This means that AE-MaaS systems (with the emphasis in on **A** in this context) must to a much larger extend be designed to sufficiently assist such users. Technology solutions need to support this.

It is expected that the **authorities** and current **transport providers** can take a major role in extending current fixed-route transport systems to AE-MaaS systems for reasons discussed above. As seen from their perspective, fixed route solutions as of today could be extended to AE-MaaS systems with new vehicles, and with some extensions to current technology solutions. Public transport authorities like Ruter, AtB and Kolumbus have taken steps towards AE-MaaS in various ways by ordering electric buses in larger quantities for fixed-route use (e.g. AtB have ordered 35 electric, but not autonomous,buses) and testing autonomous buses (e.g. Kolumbus).

The **business model** for fixed route AE-MaaS is not to different from current transport systems solutions since paid fixed route transport (in most European countries) is the responsibility of the authorities.

Electrification of the fixed route transport systems results in lower emissions and improved environmental conditions. A large portion of the costs for running transport systems are the salaries to the drivers. When these costs are reduced or removed when moving to autonomous vehicles, there exists a possibility to decrease prices for transport within the fixed route AE-MaaS system. This can further lead to increased use of the system and reduced private car use. All in all, the **sustainability** of such a model seems obvious, at least when comparing to today's solutions.

Scenario #2: On-Demand

Cities and Citizens

As said earlier, for most aspects concerning cities and citizens there is not so much difference between scenario #1 and scenario #2. However, in relation to urban densities and service level, an on-demand scenario is likely to provide better service levels at a lower cost for AE-MaaS, than a fixed-route feed-in in less dense areas.

Context and Economics

Many aspects of Context and Economics within an on-demand MaaS scenario are similar to a fixed route MaaS scenario, although differences exist as well.

In an on-demand scenario, the **vehicle** can be tailored to meet specific trip/user needs. For example, shared trips, trips with children or animals, or trips with large amount of luggage or packages. Given that the vehicles will travel on a larger part of the road network than in a fixed route scenario, obtaining authorization to utilize autonomous vehicles in an on-demand scenario will be more challenging.

As stated within the previous scenario, the **technology platform** is crucial to a MaaS system, as it should allow for payment of travel, and route planning using multiple modes and/or multiple transport providers (all 3 key elements of a MaaS system). Specifically related to scenario 2, the geographic scope of the on-demand system impacts the technology platform and data needs. As the boundary in which the vehicles can travel expands, there is likely to be a need for increased data. An on-demand service in itself requires more complex planning algorithms and a more complex booking system in order to connect with other modes in the system.

Similar to the previous scenario, in an on-demand system, high levels of ridership are dependent on understanding the **users**. A large user benefit of an on-demand system is (near) complete flexibility of the system to meet the mobility needs of customers. As with the previous scenario, a greater understanding of how access to such an AE-MaaS system would impact people's travel behavior is needed. The **transport model** would need to address the geographic bounds of the system and address any restrictions of how on-demand vehicles could be used. For example, is there a limit to the distance in which a customer can travel with an on-demand vehicle? Are there requirements that an on-demand trip must connect to a public transportation? Where are the boundaries of the service?

As with the previous scenario, within an on-demand scenario, **local authorities/transport providers** are knowledgeable about the local context. More so for the on-demand scenario, this includes insight on how on-demand vehicle could be coordinated with existing public transit options, what the geographic limits of the service should be, and feasibility of autonomous vehicle approval. As earlier, public authorities have an overarching view that users or private entities might not see, for example concerning urban mobility challenges. Public authorities also have the ability to influence, to varying degrees, mobility offerings and policies, thus can promote sustainable mobility.

It is assumed that MaaS will function as either a private initiative or a public-private partnership. Within an AE-MaaS on-demand system, a private initiative could look something like an "Uber-model" where private interests dominate the **business model**. This could have adverse impacts on both the environmental and societal sustainability of an AE-MaaS system. For example, if the on-demand portion of the journey is too cheap, people will choose to take the autonomous vehicles for the entire journey, instead of utilizing more sustainable modes like traditional collective transport or biking/walking. If, instead, the business model is a public-private partnership, the public authorities would then be able to set guidelines and regulations to ensure the system meets the needs of the community, while the private entities have flexibility to optimize the system. Aspects regarding pricing and profit must also be considered. Pricing models will be affected by the geographic size of the on-demand system and will need more flexibility than the fixed route scenario to account for huge variation in journey durations.

As with the fixed route scenario, the public authorities have the potential to set guidelines and regulations regarding the implementation of a MaaS system. If **sustainability** is an important consideration within urban mobility, public authorities ought to limit the private initiatives business models, as these give the public authorities less opportunities to shape aspects of a MaaS system to meet local sustainability goals. As discussed previously, the environmentally sustainable components of an AE-MaaS system consist of: (1) increased sustainability due to EV use, (2) increased sustainability due to AV use, and (3) increased sustainability due to shift from personal vehicles to shared/collective transport MaaS system offerings, and the service must be based on an understanding of the components of a MaaS system which impact environmental sustainability if economic sustainability and environmental sustainability are to align. This is further discussed in chapters 4 and 8 of this report.

Vehicle and MaaS Technology

Scenario #2 describes an "on-demand" mobility solution that offer transport solutions dynamically based on the users' needs (or "demands") for transport. The "on-demand" scenario typically means that the passenger, or the system by itself, arranges for transport, often up to "the last mile". Typical benefits over scenario #1 are e.g. that the passenger might be "delivered" and picked up closer to his doorstep and destinations, and that less time is spent waiting for scheduled services or for planning for getting to the bus stop at the right time. This would certainly be a benefit for elderly people or others that find it hard or inconvenient to go to a bus stop/pick-up point. All in all, the promise of a scenario #2 solution sound intriguing to its users, although there are a lot of issues that need to be handled by such a system.

A wider range of **vehicle** types would be needed for this scenario. One could imagine that the backhaul of system still would need large capacity vehicles, while the last mile distribution would require smaller vehicles. The vehicles might also need to go outside the ordinary "routes", meaning that they would drive on smaller and less maintained roads, which could have their own more or less unknown and undefined problems like poorer road markings and varying degree of winter maintenance caused by snow and ice.

The last mile could, in many cases, be handled by electric, autonomous cars or light electrical vehicles (LEVs). Also, for longer pickup rides further away from the "drop point" that need more capacity that a typical car or LEV, small AE buses like Ligier EZ10 could be used.

The **technology platform & the data** needed to handle scenario #2 to its full extent (e.g. handling any type of deviations caused by e.g. unplanned road work and road conditions, handling the users' possible requests to change destination after having boarded the vehicle, handling offline connectivity conditions) is quite extensive. Up till now, fully autonomous vehicles have mostly been demoed in known conditions with some form of supervision. When taking the full step to on-demand, off "route" systems, vehicles need to have the intelligence to make decisions by their own during the journey, while at the same type trying its best to keep the vehicle "in sync" with the rest of the system.

Standardized backend data formats exist for defining information like routes, trips, fare collected, real-time positioning info, etc. These data formats needs to be extended to handle on-demand systems, so that vehicles can be manufactured in a standardized way and then included into any on-demand-based system as seen from the backend part. It should also be considered whether standardization for ICT systems that perform similar task in the vehicle itself should be required by the system owner.

The **users** of on-demand system need to be kept informed during the trip. This is especially important in the case of unplanned deviation. For example, consider the possibility that a running trip is rerouted due to road conditions that were unknown at the start of the journey. If such a deviation initially appears to the user as something very unfamiliar, trust in the system will be compromised and users' behavior could cause safety related issues. The vehicle must therefore be able to inform the user in a trustworthy manner. All in all, if user trust is present in an on-demand system, users seem to prefer the idea of on-demand mobility.

The requirements for the **transport model** for full-fledged on-demand system that also handles the "last mile" are considerable higher on the vehicle parts, especially if deviations are to be handled well. As discussed previously, vehicles need to have enough "self-contained" intelligence to be able to make user-friendly decisions that do not compromise the users' safety, needs and expectation neither in online or offline conditions. An on-demand system needs to handle deviation from planned trip fairly dynamically while still taking the charging infrastructure in district areas into account.

Current **authorities and transport providers** will presumably play a major role in this scenario, as they currently handle public transport solutions today and have an incentive to keep their position in the transport market. Seem from their perspective, the scenario is an *extension* to the current backbone for transport based on buses, trams and other types of vehicles that are in use today. However, current providers and authorities need to extend their offers by incorporating other types of vehicles into their systems. This could either be handled by the current authorities or providers directly, or by offering an *ecosystem* where other providers (e.g. taxi operators/Über/Lyft, bicycle providers, car sharing pools and communities, etc) of today can offer their transport services to the system. Public authorities should also be aware of different regulations exist in various markets that are claimed to hinder the implementation of innovative solutions. Lastly, changes to country-wide or local legal jurisdictions are needed to allow AE-based vehicles on any roads.

The **business model** for vehicles and their technology used in the on-demand scenario depends on a lot of factors. Assuming that there will be a backbone of public transport using similar (but AE) types of vehicles as of today:

- Will the authorities open up for integration of commercial services, providers or vehicles without an extensive certifications or tender process?
- Will the vehicles be more or less standardized?
- Will the vehicles be rented or (be required to be) owned by authorities or providers?
- Who will be responsible for the safety and security regarding the use of the vehicles and their potentially caused damage on property or people?
- How will each choice on each matter affect other options when setting up the business model?

A lot of factors are in play here, and one can imagine that difference countries and different districts will take different routes towards the final, full-fledged on-demand AE-MaaS goal.

It is believed that the **sustainability model** of scenario #2 is better than the current transport situation, even when assuming that current fossil fuel cars are converted to electric use. This is substantiated e.g. by the following assumptions:

- reduced needs in the general public to own their own cars: Less resources used for manufacturing of cards and less resources used to build transport infrastructure (road, intersections, etc.) that today needs to be scaled towards the worst use case for private cars ("1 person per vehicle")
- Lower prices for mobility can be achieved due to removing the resources (wages, education, etc.) spent on drivers

7. Market Uptake

The project also considers the market opportunities for an AE-MaaS system. The introduction of an AE-MaaS system is likely to decrease the cost and inconvenience of point-to-point mobility dramatically, and lead to a considerable boost in economic productivity. Some estimates indicate that the cost per mile will be considerably lower with an AE-MaaS system than the all-in cost car owners pay to drive today, mainly due to much higher utilization rates. This will likely cause a shift away from personally owned vehicles, decreasing the demand for new for cars in the coming decades, but at the same time opening up a new multi-trillion-dollar market opportunity related to delivering AE-MaaS solutions.

Furthermore, autonomous vehicles could unleash new demand for mobility services, especially among three underserved groups: non-drivers, the elderly, and the disabled. Harper, Hendrickson, Mangones, and Samaras (2016) holds some startling projections, showing that if these three groups take start using autonomous solutions on a large scale, they could boost overall vehicle travel (in the United States) by as much as 14 percent.

The interest and considerable investments in this space done by existing MaaS-players (such as Uber (MaaS Alliance, 2017), Lyft and Didi), Original Equipment Manufacturers (OEMs) (such as Tesla, Volkswagen, BMW and Toyota) and technology players (e.g. Google) is also a testament to the significant commercial opportunity that the introduction of a future AE-MaaS system represents.

In Norway, large cities are subject to a "Zero Growth Target", which means that there should be no increase in traffic by private car, all growth must be taken by public transport, biking and walking. Thus, from the authorities' perspective, a successful AE-MaaS system would be very interesting. It could provide the public with attractive and efficient transport solutions that improve on today's solutions.

Within the market uptake, the electric component of the system can have an effect on it, since we need to rely on charging points, re-charging cycles planning, battery lifetime and similar. The Global EV Outlook 2017 from the International Energy Agency (International Energy Agency, 2017) notes that the global electric vehicle stock has reaches over 2 million vehicles in 2016, nearly doubling the figure from 2015. Norway leases the world in terms of electric car market share (the share of new registrations of electric cars in the total of all personal light duty vehicles) at 29%. A growth of 72% of public charging points in 2016 has also been seen. The report states that in the next 10 to 20 years, the electric car market will have reached a level of mass market adoption.

Similarly to the electric component, the autonomous aspect is even more challenging, since we do not have worldwide yet a wide experience of autonomous vehicles test in open traffic. The acceptance of the consumers of an AV are one of the key aspects that make directly an effect on the market uptake. While there is still a need for more knowledge on the acceptance of AVs, results from the AE-bus demonstration survey (section 5) show that the public seems open to their use. At the same time, the technology development is needed to fully implement an AE-MaaS solution. The automotive industry has indicated that level 4 vehicles will be on the road by 2020 (IEEE Spectrum, 2017). The final component will be policy which allows these vehicles to operate freely on roadways.

8. Recommendations

Needs within a demonstration

As mentioned previously, MaaS, E-MaaS, and AE-MaaS build on one another. A demonstration of AE-MaaS also then demonstrates MaaS itself, as well as E-MaaS. Given the vision of a successful demonstration which validates the concept of AE-MaaS (and MaaS/E-MaaS) and then ultimately leads to a public wide operation, we have discussed the needs and considerations of such demonstrations within a workshop session.

The validation concepts relevant to a “simple” MaaS system are also relevant to a more advanced AE-MaaS demonstration. When demonstrating an AE-MaaS system, one must also consider the state AV testing and authorization. It is assumed that during an AE-MaaS demonstration AVs are considered safe for public use, but still may be undergoing authorization, thus possibly require the use of backup drivers in the vehicles

Related to technology, data and communication was an important concern. A MaaS demonstration needs to validate an integrated communication and data platform which is capable of handling large data sets from multiple sources. The data platform needs to allow access to the services provided in the system, as well as allow for successful payment transactions. Such an integrated platform also requires validation of regulations regarding information security and privacy, especially at the interfaces between different systems. To build on a MaaS demonstration, to validate e-mobility within a MaaS system, the key issue related to technology is validation of charging technologies, capacity and availability. Within an AE-MaaS demonstration, considering technology, it is important to validate the communication systems between the vehicles and a central server/monitoring center. Information will need to be transferred between the two parties to ensure safe and secure operations. In certain situations, the central control center may need to make an emergency stop or communicate with passengers within the vehicle. The vehicle should also be able to communicate back to the central control center about disruptions along the road network (for example road construction) which may impact routings.

Another issue to consider within MaaS demonstration is the validation of customer needs and wants within a system, as well as validation of the user experience. The intent of a MaaS system is to encourage ridership that replaces personal car use. A demonstration can be used to understand what components of the system impact ridership and satisfaction. Such insights can be gathered using surveys and interviews, and the previously mentioned data platform can provide data on usage of the system (number of users, makeup of integrated trips, geographic information…). If the goal is to shift the behavior of users, it is necessary to understand the willingness of users to shift modes and provide a way to measure behavioral changes within the demonstration. By gathering information on how users are using the system, it then becomes possible to quantify the benefits of AE-MaaS, such as reduced personal vehicle use. To do this, mapping of current travel behavior is also necessary (such as was described in the earlier section: *Travel habits and travel opportunities for commuters in Trondheim, Norway*). A demonstration also needs to validate the pricing policies. It is also important to identify suitable demonstration areas. It was suggested that an appropriate demonstration area would be somewhere that there has been identified a real need for an innovative transport solution. Some demonstration suggestions in Trondheim and Vejle are suggested below.

It is important for the public authorities to consider the safety, regulations, and responsibility distribution within the demonstration. As mentioned above, this includes data transfer when considering AE-MaaS, this includes necessary applications to operate AVs. A demonstration situation allows for a step-by-step risk assessment process, which is important considering that legal considerations for AVs are still in a transitionary stage.

Demo Suggestions

In order to select a proper demonstration location, it is important to clarify the purpose of the demonstration. Related to AE-MaaS, a demonstration could be used to validate the technology platform and operations aspects of the system. Additionally, since AE-MaaS is being considered as a way to improve the sustainability of urban mobility, a demonstration can also be used to validate travel behavior changes due to the introduction of an AE-MaaS system.

Trondheim, Norway

Given that the consortium was heavily represented by members from Trondheim, and workshops took place in Trondheim, over the course of this project, demonstration locations within the city were discussed.

Campus environments often provide a good testbed for transportation innovation due to the delineated boundaries of the service network, low speed (and often low volume) roadways, and environment which is open to and encourages innovation. A demonstration location such as NTNU, with its numerous campuses, could be used to test the technology associated with AE-MaaS but it may be more difficult to assess behavior changes as personal vehicle use is already limited due to parking fees, limited through routes, and good bus service/utilization.

An office park setting was also discussed as a demonstration location. Locations with a large concentration of commuters, ample and often subsidized parking, and underutilized public transport in the vicinity can serve as good locations for demonstrators to both test the AE-MaaS technology and behavioral changes associated with the service. The area of Sluppen, discussed in Section 5 (Travel habits and travel opportunities for commuters in Trondheim, Norway), is an example of such an office park setting.

Another possible demonstration location would be in an area where there is gap between existing transport modes. In some cities this occurs where train stations are located outside of the city in center. In the case of the Trondheim transport network, this gap could be between ferry connections and the city center, as well as between nodes of the upcoming bus rapid transit (Superbuss) system and residential neighborhoods adjacent to the hubs. Such locations about validate both technology and behavior.

A final demonstration suggestion is in a location which does not have a steady demand for service, but instead surge demands, and also lacks public transport service and parking facilities. In such an area, AE-MaaS could fulfill a mobility need for which there is currently no solution. The AE-MaaS system would then be structured to operate specifically during demand surges. An example location of such a described setting would be the area of Øya, near the center of Trondheim, where a large sports and event facility is being built with a lack of transport planning. Here there is limited parking, and the nearest public transport services stop between 500 and 800 meters from the facility. A demonstrator here would be better suited to validate AE-MaaS technology, rather than behavior changes, as a lack of parking limits the other mobility options that users have.

Vejle, Denmark

In a more deliberate approach to identify demonstration locations, the municipality of Vejle, Denmark has described a guideline for a process advancing the selection of a test site for introducing an autonomous bus in a city.

New technology can be introduced in a social context for the sake of the technology, but this is often not the case in a city context. Often when the initial enthusiasm of the new technology has gone, the new technology will have to address the city vision, specific challenges or other needs. One may feel tempted to ask: “Why are we introducing Autonomous Vehicles (AV)?” In this guideline a method for working with the WHY is introduced.

<u>WHY do we want to test Autonomous buses?</u>

An internal workshop was conducted with the case of testing an AV in the city of Vejle. Based on this process of working around defining an essential WHY, which touches upon different issues, the group found that there are 5 issues that a WHY may cover for testing autonomous buses in Vejle. Figure 5 shows these issues.

The issues identified about were used to consider test sites keeping the following in mind:

<u>Technology</u>

Autonomous vehicles are capable of running 40- 50 km per hour, but all testing so far show an average speed not exceeding 15 – 20 km per hour. This is a nice speed for people to get used to the new technology, where there may be some resistance at first because there is no driver in the vehicle. On the other hand, this speed is a limit to the distance the vehicle can travel in a given time slot.

The buses on the market currently can accommodate up to 15 persons which can be a limiting factor for where the bus will be suitable. On the other hand, the size of the bus offers new possibilities for where the bus can drive, so it will be able to drive places where there is limited space, i.e. places a traditional 12m long bus cannot drive.

Autonomous vehicles are electric. This allows the vehicle to reach places that are noise-sensitive or where there is a need for less air pollution, actually giving them the opportunity to drive completely into buildings, such as shopping malls, libraries, etc. On the other hand, it can cause challenges with charging time and reach or operating time.

Technology

- Why is this new technology particular interesting to use?
- How does this new technology enhance a better city life?

Location

- What is the purpose of testing the autonomous vehicle, and is the chosen location really the best place, where the test can proof the purpose?

City life

- How can autonomous buses enhance the livability of the city?

Climate and environment

- How do we innovate new solutions around the use of AVs that will exploit the new technology to lower the collective climate impact?

Citizens needs

- How do we secure that the testing will become a success for the end user, and do we aim at a define group of people?

Figure 5: From a workshop working on WHYs and powerful questions for testing autonomous buses. Five issues were identified and formulated.

<u>Location</u>

The buses have the opportunity to support first and last mile transportation, which is often mentioned as the reason for the lack of use of public transport. The buses are running slow, and the size makes it possible for them to go very near specific stops, thereby making it possible to address the special needs of specific groups of people. On the other hand, the size of the bus can be a challenge if too many people wish to ride the bus at one time. This may cause delay and may lead to bad reputation.

City life

Autonomous vehicles are electric and emit very little noise and no local air pollutants, which opens the possibility of having them running next to crowds of people like in shopping streets, around market places and so on. They need less space and can potentially drive on sidewalks or bicycle paths, and thereby can make shortcuts compared to the ordinary traffic, be faster from A to B, take more quiet routes entering green and relaxed areas and so on. On the other hand, if autonomous vehicles are to drive in the public traffic, their speed may seem speed-limiting and even dangerous because they run slower than expected. This could be dangerous, at least for a short period until regular traffic gets used to this new element on the streets.

Climate and environment

Autonomous vehicles run electrically and thus have the potential to reduce CO_2 emissions if charged with green energy. At the same time they can ensure first and last mile mobility, and thereby increase the shift from personal cars to public transport. On the other hand, it can also be that such a mode has an advantage over the bike, by driving closer to the destination, i.e. door to door, thereby making people giving up on riding the bicycle in the benefit of using public transport. It is a two-sided coin where the modal shift is either an advantage or the opposite with regard to climate mitigation.

Citizens' needs

The autonomous vehicle is an opportunity to address a special need of a specific group of people. On the other hand, how is the security (perceived and real) of AVs that will be used during the initial testing period? Some groups, for example older people, may also feel unsafe because there is no driver or supervisor on board the bus.

Using the previously described methodology and identified issues and concerns, the municipality of Vejle has identified four possible test sites for autonomous bus testing, each of them with a different focus. They are:

Løget: a social housing district, a partially closed district with limited access and reduced speed for regular traffic. The autonomous vehicle will be able to connect the individual buildings with the existing bus service, at a route of approximately 800 meters. Focus will be on first and last mile in a public housing area and area where not everyone has access to their own car. There will be a major local focus on the autonomous vehicle, but it will not have the same general exposure as if it is running in the city center.

GreenTech Center: a business district, with the focus on first and last mile service coupling the district with the ordinary public transport service enabling access from the train station to the business district. The area contains limited ordinary traffic. The business district has a focus on technologies for green change and renewable energy they will have a natural interest in the new technology and possibilities around autonomous vehicles.

New harbor district: a newly developed residential area at the leisure harbor, with the focus on connecting the new area with the city center, train station and other public transport. The test will run in open streets with ordinary traffic. The existing bus line does not service the new harbor area, where there is both a large new residential area, new business area and the enlarged leisure harbor.

Connecting Campus: connecting the train station with a campus area, addressing the needs of students that either walk to and from the train station or find the habit of driving their own car to the campus from home convenient. The test will run in open streets with regular traffic.

A fifth proposal could be finding a suitable elderly home where the residents have the need for transportation to a local center with shops, hairdresser, doctor and so on. Additionally, there could be a route connecting the central parking facilities and the city center with shops, potentially running on the pedestrian shopping street.

Guidelines for Public Authorities to enhance sustainability in MaaS systems

Unquestionably, public authorities and companies running the public transport service in urban areas have a crucial role in "setting the rules" for a successful AE-MaaS system. This section presents the outcome from a workshop session on concerns for public authorities to ensure the greatest possible sustainability in implementing or regulation an AE-MaaS system. Since the consortium is composed of different actors with different backgrounds and competencies, the outcome of this activity is very interesting and multidisciplinary. Summarizing the actions/concerns that can be put into action/considered for public authorities, we have:

1. Public procurement vs. private market
2. Allowing flexible private involvement
3. Setting of procurement policies (enhancing environmental considerations)
4. City center "green tolls"
5. Setting up clear driving regulations
6. Reduction of parking spaces
7. Incentive pricing strategy for sharing/connecting with public transport
8. Strengthen environmentally friendly vision in routing algorithms
9. Setting up vehicles technical requirements
10. Electrification of vehicles fleet
11. Easy data sharing among all the players of the system

The strategy of the AE-MaaS system appears to be crucial towards the sustainability of the AE-MaaS system. According to the discussions that occurred during the project workshops, it is necessary to accurately plan the **balance between the public procurement of the system and the push from the private market**. While setting up a public ownership of the vehicle fleet and the MaaS platform surely helps to have a better control over the whole systems chain and awareness of the sustainability of the system as a whole, this does not allow for **flexibility to engage the private market to take advantage of opportunities** to work inside a MaaS framework. Some private companies have, in fact, substantial expertise in offering such transport systems, and allowing them to operate can surely generate a rapid knowledge growth and speed up the implementation of the system itself.

From this perspective, public authorities have the responsibility to encourage and set up a proactive synergy between them and private partners in order to define a sustainable setup of the whole system, while allowing a flexible and multi-actor system. From a business perspective, setting up some **environmental considerations inside the procurement policies** can have a strong effect as well, by forcing the private actors to consider sustainability within their systems.

From a transport regulation perspective, setting up **“green tolls”** for privately owned vehicles in some specific areas of the municipality represents a possibility towards a greener urban environment. Similar initiatives are already quite common in metropolitan areas, but coupling them with MaaS systems can be a huge incentive for users to utilize this new transport service. Allowing only “MaaS” vehicles to freely enter in the downtown or other specific areas can increase the willingness of the people to try (and then continue with) the MaaS transport option.

Driving regulations can also be a strong incentive to shift some users towards the new transport system, e.g. giving the right of way to AE-MaaS vehicles, allowing only AE-MaaS vehicles on certain pieces of infrastructure. From a planning perspective, public authorities can also **reduce the available parking spaces** in order to passively induce more users to shift to the AE-MaaS mobility. Although it is important to note here that this procedure should minimize the induced discomfort for daily mobility, since this approach does not generate a positive perception towards the new AE-MaaS mobility concept, but instead may result in wide disapproval towards public policies/measures/decision.

The transport strategy should also consider an accurate **pricing strategy** to enhance sharing and connecting with already existing high capacity public transport services. This can be done in cooperation with experts from academia and transport analysis companies. At the same time, improving the existing services in order to be smarter/more connected/more sustainable/safer still needs to remain a priority. The synergy between existing public transport and new transport services should also be enhanced by **sustainability visions inside the routing algorithms**. Although these technicalities are generally handled by specialized companies/departments which generally lies out of public authorities offices, public authorities still the power to lead the guidelines for defining the general rules keeping sustainability as a main target.

From a technical perspective, the vehicle technology plays an important role in the system as a whole, and similarly to other equipment that is onboard, also AE-MaaS vehicles should adhere to **vehicle regulations/requirements** set by the public authorities in order to offer an acceptable level of sustainability. **Electric fleets** should, in that sense, be a “must.” Public authorities should not allow fossil-fueled vehicles within an AE-MaaS system, and they should proactively work to improve and grow the electric power supply infrastructure grid. Issues such as building more charging point, incentivizing research in fast and wireless charging should be priorities. Furthermore, as stated previously, the **sharing of data** among the AE-MaaS actors have to be ensured. A fluent data transfer between all the levels of the system can improve the efficiency and sustainability of the system in many ways, for example, it is needed to make accurate decisions within routing algorithms. From this point of view, setting up standards that require “open access/sharing” among the actors involved in the AE-MaaS system should be prerequisites that public authorities should aim to when defining rules and policies.

9. Feasibility

Taking advantage of the multidisciplinarity of the consortium, partners were asked to brainstorm major factors affecting the feasibility of an AE-MaaS. The ability to tackle this task from different backgrounds allows us to highlight factors affecting the system from many angles. The identified factors have been grouped into specific components of an AE-MaaS system as shown below. These feasibility factors should be considered during the development and implementation of an AE-MaaS system.

Users

US1. Customers' Needs: The ability of the system to accommodate the customers' needs instead of imposing/proposing a completely different/new transport service

US2. Customer identification: The investigation/identification of the most likely potential customer group (instead of proposing the system to a selected audience, such as students, youngsters, elderly, etc…)

US3. Public response / willingness to change: The intention of the users to accept a new way of transport that can potentially induce them to abandon ownership of a vehicle

US4. AVs public acceptance: The readiness of users to trust and accept AVs in the daily routine and in full operational environments

US5. Ethical aspects in critical situations' decisions: Understanding and consensus of the potential ethical dilemmas that could occur in which AVs needs to take critical decisions

App/Platform

APP1. Booking app: The smoothness/ease of use of the dedicated user app/platform

APP2. Integrated payment systems: The possibility to pay for transport services inside the app/platform

APP3. Communication between users/system: The possibility for the user to communicate with the app/platform but also with the vehicle.

APP4. Information security: The security and safety of AVs operating data, AVs control systems, users' privacy.

APP5. Multimodal data integration: The integration in the app/platform with different transport modes, offering optimized multimodal transport solutions

APP6. Transparent/correct data sharing between parties: The willingness to share information between all the operating parties involved (government, industries, users)

Vehicle Technology

VT1. Vehicle comfort: The quality of comfort offered in the vehicles, considering all transport modes

VT2. Vehicle design: Specific design issues/features that need to be addressed

VT3. Self-driving level/capabilities: The levels of operating AVs (SAE levels) and their influence on the overall quality of the AE-MaaS system

VT4. Autonomous vehicle regulations: The set of regulations/norms that are necessary for AVs to be tested, and operated in open traffic

VT5. V2V communications: The ability of vehicles to communicate among themselves in real time

VT6. AV Technology readiness: AV technology at a status beyond a "beta" version but instead a fully operational/capable technology (different from AVs levels, because it is possible to have a fully developed AV but with only SAE level 2 or 3 abilities)
VT7. AVs in adverse/winter weather conditions: The effect of adverse and winter weather conditions on the ability of AVs

Electric Technology

ET1. Vehicle charging opportunities: The amount of charging points/platforms/areas that will be available for operating EVs in the AE-MaaS
ET2. Mixed & sustainable electric source: The environmental impact of generating such a large amount of electrical energy needed to fulfill all AVs demand
ET3. Power-grid capacity of absorbing electric request: The capacity of the power-grid/infrastructure to satisfy the increasing electricity demand without reaching critical conditions (overcapacity, demand peeks, etc…)
ET4. Battery capacity: The amount of energy that can be stored in batteries onboard the EVs

Business Model

BM1. Pricing strategy: The price of the service and its flexibility in terms of possible period subscriptions, one-trip tickets, multimodal trips with one ticket, etc…
BM2. Financing: The ability of the transport system to sustain itself without heavy contribution from the public service
BM3. Vehicle ownership: The choice of letting the service/vehicle fleet be owned by the public authorities or private companies
BM4. Critical mass involvement to explode MaaS usage: The need for the system to reach and capture a critical mass of users in order to then assume a large scale and result, to be effective on the society/environment/cities flows
BM5. Business risk acceptance / risk of failure: The level of acceptance from private companies and government to explore a transport system that can end up a flop
BM6. Marketing: Advertising the system among users and interested transport companies
BM7. Long time perspective: The potential of such a system to represent a long term and time durable transport option for cities

Transport & policy

TP1. Vehicle routing: The effectiveness of selected routes for the integrated transport services
TP2. Vehicle sharing capabilities: The potential offered by the system to the users to share trips with others users
TP3. Operating area: The identification of an operational area inside which the AE-MaaS system is functional and operative
TP4. Multimodality: The level of multimodality transport offered by the system
TP5. Fixed route vs. On-demand transport service: The strategic choice between on demand and fixed route based AE-MaaS transport services
TP6. Adaptation of traffic rules: The need to adapt and innovate traffic rules in order to accommodate AVs and new type of vehicles
TP7. Adaptation of transport infrastructures: The need to adapt and innovate the whole transport infrastructures (roads, railways, cycling lanes, sidewalks)
TP8. System management / A.I.: The intelligence of the system to provide a highly flexible and customizable transport choice to the users thanks to advanced routing algorithms/intelligences

TP9. International rules homogenization: The need for an homogenization of rules and policy among countries in order to offer transnational transport services

TP10. AVs Insurance liability/coverage: The management of legal liability for AVs in case of accidents/injuries/fatalities

TP11. Ability to attract desired users: car drivers vs. bikers: The ability to induce a modal shift in the right way: incentivize current car drivers to use the AE-MaaS instead of attracting cyclists and pedestrians

TP12. Political willingness to establish such a system: The political intention to incentivize and establish such a system instead of letting it be proposed and controlled by the free market

TP13. Integrating with public transport, not competing: The level with which the system is able to integrate to the existing transport services instead of competing with it

10. Conclusions

Concluding thoughts

This Climate KIC Pathfinder project involved of a large consortium with many areas of expertise, which is appropriate given the many aspects which need to be considered within the exploration of Autonomous E-Mobility as a Service. The different partners, coming from industry, government, and research, brought different perspectives, interests, and ideas to the discussions with in the projects. The work within the Pathfinder project remained broad and considered a wide scope of AE-MaaS development, not to limit options early for a demonstration project.

The concept of AE-MaaS was considered in three layers - a MaaS system at the base, with additions of electric mobility and autonomous mobility. Within the consortium discussions, we considered whether e-mobility was “a given” and concluded that while there are still challenges associated with fully electrifying the transport sector, there are many whose work focuses on solving these challenges and it is not unreasonable to assume the electric mobility as a service is feasible. Regarding autonomous vehicles, we acknowledge that there are many unknowns within their implementation into the transport system. This includes timeline to full autonomy (SAE level 4/5), regulations for testing, and regulations for public operations. Such uncertainty may suggest that the choice of a fixed route AE-MaaS scenario is more realistic to consider for a demonstration in the near future (for reasons regarding testing regulations and where AVs are allowed to operate). However, such a fixed route demonstration can inform future on-demand scenarios. Similarly, there is likely value in demonstrating a MaaS system without an autonomous feature (if authorization is not given) in order to gain knowledge, as described below.

During the numerous discussions which place during project meetings and workshops, several elements were mentioned numerous times. The concepts of (1) communication and data transfer within a technical framework, and (2) needs and wants of users were identified as areas where more knowledge and experience is needed in order to build a successful AE-MaaS system. Understanding the needs and wants of users is specifically important if the goal of an AE-MaaS system is to improve the sustainability of urban mobility, largely through the reduction of personal vehicle miles travelled.

Environmental sustainability within an AE-MaaS system is not a guarantee. If an AE-MaaS system is developed without sustainability thinking in mind, there is a risk that the system could promote unsustainable behaviors, such as failing to attract users who are currently using private vehicles, attracting users from more sustainable modes (cycling and walking), and inducing additional individual travel by not limiting the use of autonomous vehicles. The public authority is likely to need to take an active role to secure sustainability, either by taking an active role in the development of the system, or instituting procurement policies which require and/or reward sustainability within a private system.

The demonstrations and adjacent projects discusses within section 5 of the report illustrate that the technology is developing rapidly and largely accepted by the public (Helsingborg Demonstration), public authorities are interested in implementing MaaS concepts (Trondheim Taxi Pilot), and there is are potential markets where an AE-MaaS service could motivate people to move from their personal vehicles to more sustainable mobility options (Sluppen Travel

Survey). To fully demonstrate and validate an AE-MaaS system, legal acceptance of autonomous vehicles is required. At the same time AE-MaaS is dependent on the timeline of advances in autonomous technology.

Next steps

At the final workshop, the consortium discussed their thoughts on next steps within the project. Within the ClimateKIC framework, Accelerator and Demonstrator projects often follow Pathfinder projects.

Defining the right leadership

The discussion on future work began with the question: who is the right person(s) to lead future Accelerator or Demonstrator projects? The concept of AE-MaaS involves complex transitions, overlapping areas and scopes, and collaborative thinking. Within our Pathfinder project, a wide scope has been kept when looking at the potential development and implementation of an AE-MaaS system. This was, in part, because the project leaders were from academia (NTNU) and thus did not have a specific demonstration location or situation as a personal/institutional objective. The diversity of the consortium lead to many interesting suggestions on where and what could be tested within a demonstration, most often focusing traveler behavior (how to get people off their cars and into a MaaS system) or how the technology works (seamless integration of modes). Additionally, considering an AE-MaaS system, a demonstration can also test how autonomous vehicle technology can be applied within an urban context.

It has been suggested that those providing the service (public transport) could potentially drive a successful Accelerator/Demonstrator project. Public transport companies interact with public authorities in the areas they operate, are knowledgeable on technologies used in operations/planning/ticketing, and have direct contact with users. Similarly, public authorities in Norway have a responsibility for regional public transport and often have mobility objectives they aim to achieve. Thus, a public transport company or public authority is proposed as the project lead on any demonstrator follow up projects related to an AE-MaaS system.

Relying on a collaborative policy/legislation approach

Before proceeding with further project development, several conversations were suggested. Given that a successful AE-MaaS demonstration depends on authorization by the National Public Road Authority (NPRA in Norway, similar in other Nordic countries) to operate an autonomous vehicle on the public roadway, it is important to understand their plans and goals regarding autonomous transport. As of January 2018, autonomous vehicle testing will be allowed in Norway. Confirming where and how AV operations will be authorized is crucial before deciding on a demonstration site. The city of Kongsberg (Norway) has been designated a test arena for AV technology, although this location may not be conducive to AE-MaaS demonstrating due to the expected effects of population density on the operations of an AE-MaaS system[4]. It was also suggested to take contact with Applied Autonomy during demonstration development. Applied

4 The population (density) of Kongsberg is ca. 21 269 people (1726 people/km2) versus ca. 177 617 people (3090 people/km2) in Trondheim, for example. (reference: https://www.ssb.no/en/befolkning/ statistikker/beftett)

Autonomy[5] is a company that offers services related to implementation of demonstrations and testing of autonomous vehicles. Applied Autonomy is involved within the Kongsberg Test Arena as well.

Narrowing down the scope towards a specific demonstration project

The ideas developed and discussed within the AE-MaaS Pathfinder project must be narrowed down and specified for a specific need and location in order for a successful demonstration. It is believed that the contents of this Pathfinder report provide a foundation for continued discussions to identify a successful demonstration opportunity for the idea of Autonomous, E-MaaS. There are still questions related to the information technology platform, travel behavior and acceptance of AE-MaaS users, and full financial feasibility of the system, but these aspects can be further explored within a demonstration scenario.

5 http://www.appliedautonomy.no/

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