MIND sets

Future trends in mobility: the rise of the sharing economy and automated transport

Deliverable n. 3.3 -Annex A

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Contents

Preface

This document is a technical annex to Deliverable 3.3 of the MIND-SETS project. This annex follows the same general structure as the main document, but delves deeper into the arguments, tackles the technical issues in greater depth and contains a full reference list.

Chapter 1: The rise of the sharing economy: implications for transport

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1. Introduction

It was easy to predict mass car ownership but hard to predict Walmart

Carl Sagan

Previous Deliverables in the MIND SETS projects1 had already pointed to the rise of the "sharing economy" in Europe. For instance, between 2006 and 2014, the number of users of carsharing systems has increased from 0.36 million to 4.95 million. Bike ridership has also experienced a sharp growth over the last 10 years.

In a few years' time, these services have escaped from their niche status, and are arguably moving in the mainstream. Some urban transport planners are already wondering to what extent these new market models will undermine the assumptions of their current work. Moreover, several sectors are already affected by the phenomenon: taxi drivers argue that on-demand ride services are a form of unfair competition, traditional car rental and even car manufacturers are moving in the car sharing business, public transport operators wonder whether these new transport models are competitors or possible strategic allies… Moreover, there are indications that shared mobility may not only replace some forms of private travel, but may also facilitate other forms of private travel. Hence, the net environmental and transport impacts remain contentious.

Moreover, whereas the idea of fully autonomous cars looked like pure science fiction just a decade ago, several major players claim that they have developed prototype models that can function in operational circumstances. Although there is a lot of controversy regarding the speed with which autonomous cars will indeed gain important market shares, no one seems to doubt that, in the long run, they will replace human operated vehicles. Paradoxically, although no one questions that their impact will be profound, there is a lot of debate on whether these impacts will be beneficial or detrimental. As we shall discuss below, it is likely that the beneficial impacts will only be fully captured if autonomous vehicles are integrated in a "shared mobility" business model and if they are complemented by high-capacity transit systems.

A third major game changer is the likely breakthrough of alternatives to the internal combustion engine (ICE) in the coming decades, and especially of electric vehicles (EV). Major breakthroughs in battery technology have improved the competitive position of EV, even though the most performant models still target mainly an affluent niche audience. Until recently, electric vehicles face two major disadvantages compared to ICE vehicles: their limited range and their large acquisition cost. Interestingly, "shared mobility" market models are better equipped to deal with these two issues than mobility models based on personal car ownership.

Summarizing, a strong case can be made that three important developments in the mobility sector (shared mobility, autonomous vehicles, electric mobility) can be mutually reinforcing, and lead to profound changes in our mobility systems.

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[1] *Deliverable no. 2.1, Understanding the role of mobility in the changing lifestyles of Europeans: coordinating what we know, Chapter 1: Mobility mind-sets mapped across Europe*

Before proceeding, we need to realize that "shared mobility" can mean different things to different people. Key terminology in the field is often used without rigorous definitions, and this can be an important source of confusion.

We will therefore first define the term. We will the definition proposed in Shaheen et al.(2015a): shared mobility is a "transportation strategy that enables users to gain short-term access to transportation modes on an "as-needed" basis".

This concept covers a wide range of services, ranging from 'traditional' services such as carsharing, carpooling, microtransit and bicycle sharing to services that have just emerged in the last few years, such on-demand ride services. In broader definitions, it also includes the smartphone apps that enable the implementation of these services (Shaheen et al.2015a). The definition is thus broad enough to cover most services that people would recognize as being "shared services".

The growth in "shared mobility" parallels the more general trend towards shared marketplaces for instance in the hospitality sector and in household and gardening tools. The following three factors have been identified as critical for the success of such shared marketplaces (ITS America 2015): the establishment of trust, the provision of peer review, and the swift fulfilment of needs. As we shall see below, Internet technologies and mobile apps have played a key role in each of these factors.

The key promise of the sharing economy is a more efficient utilization and monetization of assets that are not used to their maximum capacity. "Cars, as expensive household line items with low daily usage rates, are prime for this." (ITS America 2015)

In this chapter, we thoroughly review the existing evidence and these advantages and drawbacks, drawing from the peer reviewed scientific literature, the "grey" literature and discussions in the popular media.

In our discussion of shared mobility, we shall follow the classification used by Shaheen et al. (2015a) in a recent review of the topic:

- Carsharing
  - Roundtrip Carsharing
  - One--Way Carsharing
  - Personal Vehicle Sharing (PVS)
- Scooter sharing
- Bikesharing
- On--demand ride services
  - Ridesourcing/Transportation Network Company (TNC) Services
  - Ridesplitting
  - E--Hail Services
- Ridesharing: carpooling and vanpooling
- Alternative transit services
  - Shuttles
  - Microtransit
- Courier network services
  - P2P Delivery Services
  - Paired On--Demand Passenger Ride and Courier Services
- Trip planning apps
  - Single--Mode Trip Planning

- Multi--Modal Trip Aggregators
- Gamification

Moreover, we add a discussion on automated mobility, and how synergies are possible between automated and shared mobility concepts. We will also discuss what these emerging mobility concepts imply in terms of transport modelling and data collection. We conclude with a discussion of the policy implications.

We shall not explicitly cover the topic of parking place sharing, this is a business model that allows "homeowners and businesses to rent out their unused parking spaces."[2,3] , although this could be a useful topic for new research. One avenue that could be particularly interesting is to have building blocks renting excessive parking capacity to carsharing systems. Alternatively, this excess capacity could be used to install bicycle parking, or to manage a shuttle system from the housing block to public transit stations[4].

Neither shall we discuss business models where individual components (the example that comes to mind are batteries[5]) of a car are rented, rather than the car in its entirety (Weiller and Neely 2013).

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[2] http://intelligentmobilityinsight.com/news/CWJ

[3] https://en.wikipedia.org/wiki/Shared_parking

[4] http://mobilitylab.org/2016/01/15/three-parking-alternatives/

[5] A closely related alternative is to share loading points for cars, which is already being done – see https://chargedevs.com/newswire/swedish-initiative-lets-ev-owners-share-charging-stations-a-la-airbnb/

2. Carsharing

2.1. Definitions

Le Vine and Polak (2015) acknowledge that drawing the boundaries between carsharing and car rental is a vexed issue: "one view of the term is broad enough to encompass traditional car rental, whereas a contrasting perspective would emphasise the importance of intermediation via contemporary ICT, thereby excluding car rental from a storefront or airport counter."

Let us therefore consider two definitions proposed in two recent authoritative reviews of the subject.

Le Vine et al. (2014) propose the following definition for car sharing:

- The user must go through a qualification process once. From then on, he is able to access the service's cars with no need for interaction with a member of staff.
- The vehicle is driven by the end user as in traditional car hire. The end user may be making use of the vehicle on a personal basis, or on behalf of an employer (corporate carsharing).
- Usage is billed in time increments of minutes or hours, and sometimes also on the basis of distance travelled. Daily rates are typically higher than for traditional car hire, even if multi-day usage at discounted rates is sometimes allowed.
- There may be a one-time sign-up fee or an annual subscription fee, on top of the variable charges.
- Usage is in some cases spontaneous and in others reserved in advance.
- The vehicles are typically available from distributed locations across a service area - in traditional car hire, vehicles are accessible only from a small number of locations (such as airports).
- Servicing/cleaning is done by the operator's staff on an occasional basis, rather than after each usage.

Le Vine et al. (2014) argue that, although the term carsharing remains in use for historical reasons, it would be more accurate to describe the behaviour as *sequential short-term car access in-exchange-for-monetary-payment*.

Shaheen et al. (2015b) provide the following alternative definition: "Carsharing is generally defined as short-term vehicle access among a group of members who share a vehicle fleet that is maintained, managed, and insured by a third-party organization. It is typically provided through self-service vehicle access on a 24-h basis for short-term trips."

Compared to traditional car renting, common elements in both definitions are the emphasis on short term access and on the possibility for the members to access the cars without intervention of the third-party organisation.

One possible source of confusion is that, in the UK, "carsharing refers to multiple people travelling together in a car at the same time", which in other countries is referred to as

carpooling or ridesharing. In the UK, the term "car clubs" is used instead of carsharing (see Le Vine et al. (2014) and Shaheen et al. (2015b)).

The market consists of the following subcategories (Shaheen et al.2015):

- Roundtrip carsharing, where "users must return vehicles to the same location from where they were picked up
- One way carsharing , "which allows members to pick up a vehicle at one location and drop it off at another"
- Personal vehicle sharing

We shall discuss each subcategory in further detail later in this chapter.

2.2. Key advantages and drawbacks

Compared to car ownership, carsharing is characterised by the following advantages and drawbacks (see Shaheen and Cohen (2013) ; Le Vine et al. (2014); Ciari et al. (2015); Fournier et al. (2015) ; Greenblatt and Shaheen (2015) ; ITS America (2015) ; Wadud et al. (2016) and Shaheen et al. (2015a)):

- Carsharing takes several burdens associated with car ownership away from the car user: finding (and paying for) permanent parking, periodic vehicle inspection and taking care of adequate insurance cover. If these activities are characterised by economies of scale, they can be undertaken more efficiently by carsharing companies than by individuals. Moreover, carsharing shifts the burden of maintenance and repair costs to the operator. The last category of costs can be both uncertain and large, and a carsharing operator will be able to pool these risks.
- Carsharing reduces the fixed cost of car use to periodic membership fees. As a result, variable cost become relatively more important and salient in travel decision making, and may lead to a decrease in travel demand[6,7].

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[6] For a discussion on the importance of the salience of cost elements in decision making see Section 5.2 of Deliverable no. 2.1 of MIND-SETS.

[7] From a behavioural economics perspective, it is interesting to note that these issues are not always understood correctly by people contemplating a move to carsharing. For instance, a recent survey in Vancouver showed that "a majority of Metro Vancouver car owners (57%) acknowledge that the benefits of carsharing would make them contemplate selling their car, including 85% of Millennials and 55% of Generation Xers. Savings from vehicle maintenance (37%) and fuel costs (34%) are the most attractive features of carsharing among car owners who would consider shedding their vehicle." Of course, as vehicle maintenance and fuel costs are variable rather than fixed costs, this motivation completely misses the whole point of carsharing www.insightswest.com/news/carsharing-entices-metro-vancouverites-to-sell-their-cars/

- Below a threshold of annual kilometers traveled (which can vary from 10,000 to 18,000 kilometers), carsharing can be cheaper than owning a car. Carsharing can thus increase mobility options for people with limited financial resources (which was actually the motivation behind the first carsharing schemes).
- Carsharing supports active lifestyles by encouraging bicycle and pedestrian travel modes.
- Because cars are used more intensively, there is a quicker turnover of the fleet, and older models are replaced more quickly by (presumably) cleaner new models. Vehicle will also increasingly be purpose-built for sharing, which could lead to a virtuous cycle of decreasing costs. It could also lead to a quicker penetration of "connected" cars who could collect and transmit data on air quality, road condition, vehicle speeds, etc.
- Vehicle sizes can be adapted to the trip purpose and the number of passengers. As a result, it is expected that manufacturers will build even smaller and lighter vehicles, or that larger vehicles will have higher occupancy rates.
- As shared vehicles have a higher annual mileage than privately owned cars, there is a stronger incentive to increase energy efficiency or to switch to powertrains with lower variable costs (such as battery electric or hydrogen fuel cells)[8]. Moreover, if shared vehicles are mostly used for short trips, one of the main barriers to the use of battery electric vehicles (range anxiety) disappears.
- For mobility impaired people, sharing a car that is wheelchair accessible allows the spread the (high) acquisition cost of this car.
- On the downside; if the user has to indicate in advance the duration of the rental (as is mostly the case), then he must either pay for time that was reserved but remained unused, or run the risk of being penalized for returning the vehicle too late.
- Moreover, carsharing operators offer no guarantee that a car will definitely be available when and where desired. For instance, in the case of Cambio carsharing, 1 in every 15 requests is not accommodated to the user's satisfaction. However, if fleet sizes increase further and prediction techniques become more performant, pricing mechanisms could be developed that could better match the users' willingness to pay for reduced risk of unavailability.

Balck and Cracau (2015) point out that environmental motives can also play a role in the decision to join a carsharing scheme, but that competing modes such as public transport can also appeal to the same motives. However, besides the environmental motives, "good and easy access to cars is important to potential users of car sharing services".

2.3. A (very short) history of carsharing

As discussed in Shaheen and Cohen (2013) carsharing began in Zurich (Switzerland) in 1948 with a cooperative known as Sefage (Selbstfahrergemeinschaft), which operated until 1998. The main objective of Sefage was to give access to car mobility to people who could not afford to buy a vehicle. A series of other carsharing experiments were subsequently attempted in Europe but all eventually had to cease operations. The modern version of carsharing took off in the

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[8] As we shall discuss further (see Section 2.5), several carsharing services include electric vehicles in their fleet. At the time of writing (July 2016), there was one carsharing who also offered services with fuel cell vehicles http://www.autoblog.com/2016/04/10/world-first-fuel-cell-carsharing-program/

second half of the 1980s, in Switzerland and Germany. It further spread throughout Europe and the rest of the world, with important developments in the first decades of the 21st century.

However, it is only in the last five years that carsharing has really started growing exponentially. This can to a large extent be attributed to advances in digital technology which have made the "process of reserving, paying for, and locating cars easier, while digital unlocking and verification services have eliminated the hassle of keys" (ITS America 2015).

According to Shaheen and Cohen (2016); as "of October 2014, carsharing was operating in 33 countries, five continents, and an estimated 1,531 cities with approximately 4.8 million members sharing over 104,000 vehicles. Europe, the largest carsharing region measured by membership, accounts for 46% of worldwide membership and 56% of global fleets deployed. (…) As of October 2014, one-way carsharing accounted for 17.6% of global membership and 23.3% of global fleets deployed (based on data provided through expert interviews). As of October 2014, roundtrip carsharing accounted for 82.4% and 76.7% of global membership and fleets deployed, respectively. (…). Europe had the greatest percentage of one-way fleets regionally, representing 31.1% of the continent's carsharing fleet. (Note: Numbers reflect business-to-consumer (B2C) carsharing only, including one-way operations.)"

According to Marsden et al. (2015), growth has been most pronounced in Belgium, Germany and The Netherlands. In Brussels, for instance; 9000 members shared 270 cars in 2014. Growth across Europe (and worldwide) is concentrated in urban areas.

The rapid growth of carsharing is illustrated in *FIGURE 1* and *FIGURE 2*. The growth from around 250,000 members of carsharing systems in 2006 to more than 2,000,000 members in 2014 is certainly spectacular. However, to put these figures somewhat in perspective, in 2011, the total number of people in the EU29, Liechtenstein, Norway and Switzerland that had reached the "driving license age" (18 year or older) exceeded 400 million. Thus, actual membership of carsharing systems in Europe amounts to around 0.5% of the population of driving age.

Thus, while carsharing has grown rapidly, we need to take seriously the possibility that mobile apps have helped this business to break through one ceiling, just to hit another one in the near future. Alternatively, one may argue that positive experiences with carsharing will lead to further growth, and that critical mass will lead to step changes in the efficiency of carsharing efficiency, which could lead to a virtuous circle.
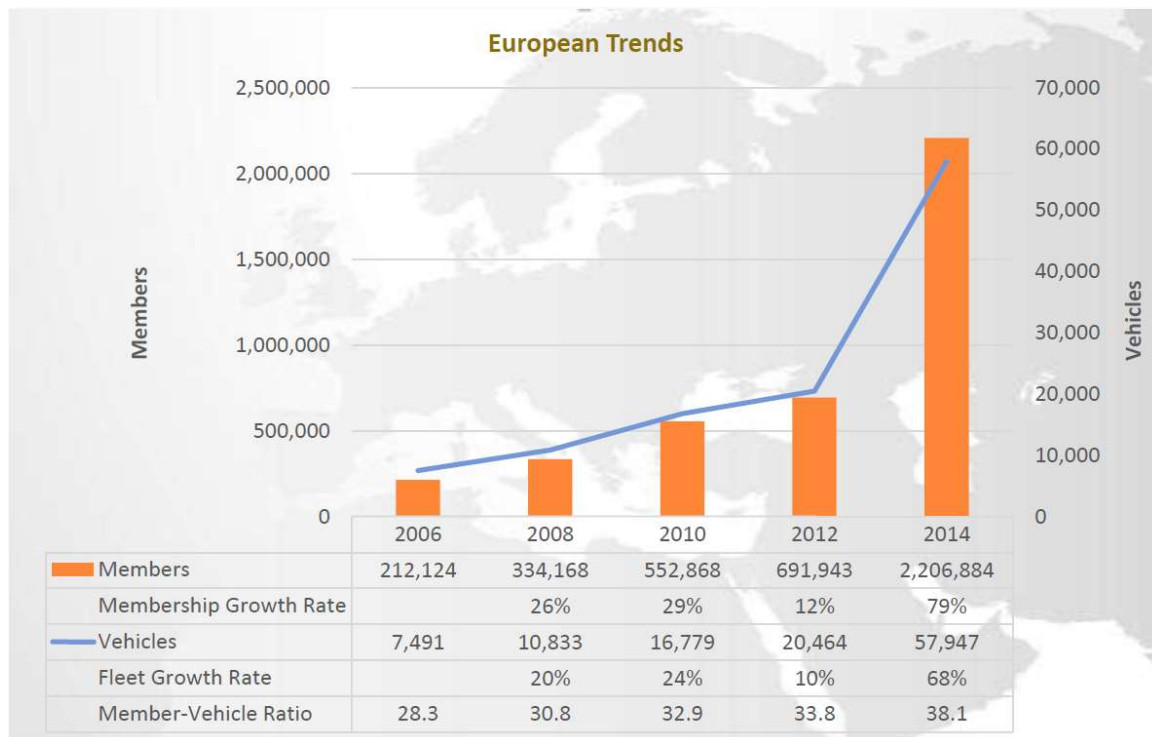
FIGURE 1- EUROPEAN TRENDS IN CARSHARING. SOURCE: SHAHEEN AND COHEN (2016)
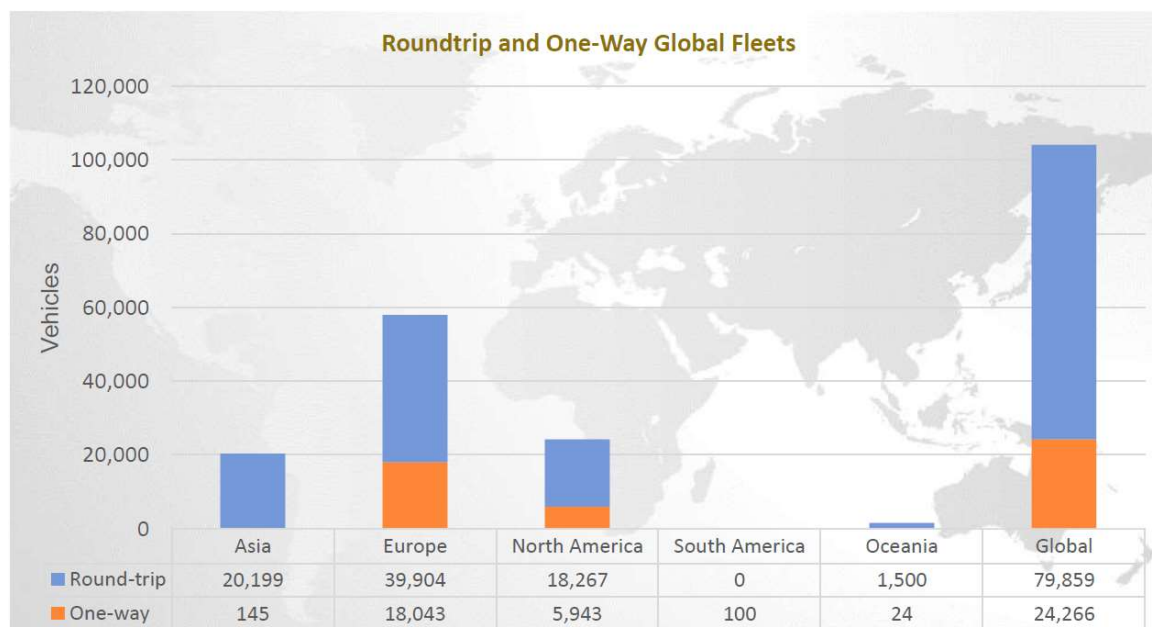
FIGURE 2- ROUNDTRIP AND ONE-WAY GLOBAL FLEETS SOURCE: SHAHEEN AND COHEN (2016)

2.4. Round trip carsharing

Shaheen et al.(2015a) define round trip carsharing as a service model which allows "members hourly access to a fleet of shared vehicles" where "users must return vehicles to the same location from where they were picked up." In this model, the cost "is a combination of annual or monthly fees, as well as time and distance costs". Carsharing is offered both in the B2C and the B2B segments.

Other key characteristics of this model is that cars are usually reserved in advance (via smartphones or websites), that the fleet is centrally owned (or leased) by a professional carsharing operating entity and that the vehicles are allocated dedicated parking spaces (Le Vine et al. 2014). If the dedicated parking spaces are on-street, permission from the street network manager is required. As local governments mostly have a monopoly on the use of streets space, obtaining this permission is of strategic importance of carsharing operators (Le Vine et al. 2014).

4 HOUR USE – Europe
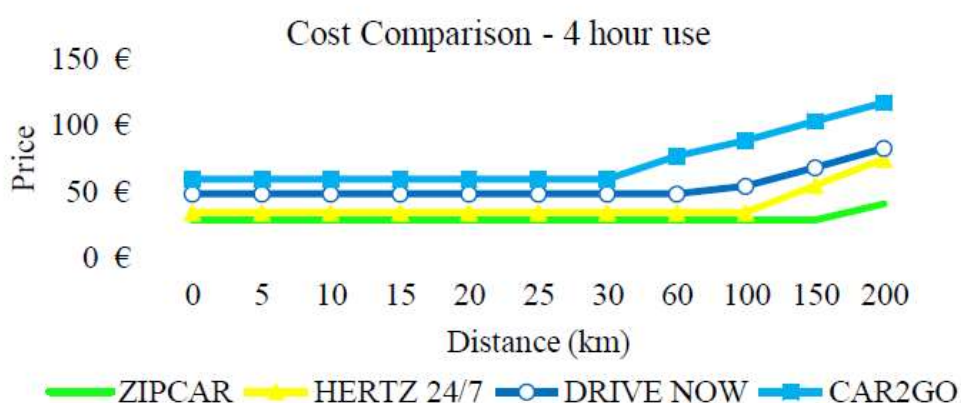
FIGURE 3: PRICES 4 HOUR USE EUROPE CARSHARING (SOURCE: GONZÁLEZ-IGLESIAS BAEZA 2015)

2.5. One way carsharing

Shaheen et al.(2015a) define one-way carsharing (or point-to-point carsharing) as a system which "allows members to pick up a vehicle at one location and drop it off at another".

Within the category of "one way carsharing", a further distinction can be made between (Greenblatt, and Shaheen 2015):

- one-way-station-based; the vehicle is returned to a different designated-carsharing location, and

- one-way free-floating[9]: the vehicle can be returned anywhere within a geo-fenced area[10]

In the case of station-based one-way carsharing, fixed infrastructure (for instance charging points for electric vehicles and customer service kiosks) can be located at the parking stations. Compared to a point-to-point free-floating system, the logistics of a point-to-point station-based system are easier to manage (Le Vine et al. 2014).

Kopp et al. (2015) argue that free-floating car sharing models have been developed as a response to the lack of flexibility of traditional station-based carsharing. Another advantage, pointed out by Shaheen et al.(2015a), is that "(o)ne-way carsharing (…) has the potential to further enhance first- and last-mile connectivity." Note that this last point is especially important if one wishes to promote carsharing as a complement to public transit, rather than as a competitor. According to Shaheen et al.(2015b), almost "70 % of roundtrip operators viewed one-way car sharing as a complement to roundtrip car sharing, while 19 % viewed it as a competitor. Twelve percent perceived it as both a complement and competitor".

Despite its advantages, compared to "round trip" carsharing, the rise of "one way" systems is relatively new: according to Shaheen et al.(2015a), one-way carsharing has mainly expanded since 2012, and operates now in seven countries. This relative recent uptake can be better understood by looking at the key elements enabling "one way" systems (Shaheen et al. 2015b):

- Technology; smartphone applications, keyless vehicle access, in-vehicle and mobile global positioning system (GPS) receivers, and hybrid and electric vehicles (EVs)
- Public policies that enable private firms to reserve on-street parking[11].

The two largest operators in this market segment (Car2Go and DriveNow) actually belong to car manufacturers (Daimler and BMW, respectively). Car2Go was initially launched in Ulm (Germany) in 2009. It currently operates in 26 European and North American cities with fleets ranging from 250 to 1200 vehicles (Firnkorn and Müller 2015; Schiederig and Herstatt 2014). DriveNow started its operations in Munich and Berlin in 2011, and has subsequently expanded in Germany and in the US (Kopp et al. 2015). DriveNow currently also operates in Vienna, London, Copenhagen and Stockholm, and 20% of the cars in operation are electric[12]. Ford has also moved in the one-way carsharing business with GoDrive. At the time of writing, its operations were limited to London[13].

BMW has now launched an "enhanced" version of DriveNow under the brand name ReachNow14. At the time of writing, the service was limited to Seattle, but BMW has expansion plans to other cities in the US. Besides the fact that the car is delivered directly to the customer, the most

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[9] Also referred to as "flexible carsharing" (Le Vine et al. 2015).

[10] Reservation is typically just a few minutes in advance (Le Vine et al. 2014). Available cars are identified with smartphones (Firnkorn and Müller 2015)

[11] As pointed out by Le Vine et al. 2014, a "contractual arrangement with the entity that manages on-street parking is generally required; typical agreements involve the payment of an agreed sum in exchange for the right for customers to park in any (or nearly any) legal on-street parking space."

[12] http://intelligentmobilityinsight.com/news/Cs1

[13] http://www.theverge.com/2015/5/26/8659553/ford-godrive-car-sharing-london

[14] http://intelligentmobilityinsight.com/news/Cs1

remarkable about this service are a number of features that blur the line between carsharing and alternative sharing mechanisms:

- the car can be used for a longer period, which is typical for conventional car rental
- customers can rent their own car via the services, which is the core business of personal vehicle sharing (see further)
- customers can ask for a car with driver, which puts the service in direct competition with on-demand ride services (see further)

Moreover, a pool of vehicles can be made exclusively available to closed groups such as companies or residential complexes.

According to Ciari et al. (2015), in "many cases, free-floating carsharing came to cities where a traditional, round-trip carsharing program already existed.(…) Such 'heavy-weights' entered the market with a 'big bang' approach—meaning starting operations in new cities with a large number of cars all at once".

Both types of point-to-point carsharing suffer from tidal flows which can lead to clustering of vehicles (Le Vine et al. 2014). Thus, compared to round-trip carsharing, one-way carsharing requires more non-revenue generating movements to re-position vehicles[15]. On top of this, users run the risk that a car will not be available for a return journey (Nourinejad and Roorda 2015).

One possible approach to these problems is to provide incentives to customers to re-position vehicles. For instance, the French carsharing system Autolib offers free rentals for this purpose – see Le Vine et al. (2014).

Several researchers have also investigated complex models to deal with issues such as optimal fleet sizes, station location, vehicle relocation and incentivising users to drop vehicles at specific locations (see Shaheen et al.2015b for an extensive discussion).

Despite all the challenges, one-way carsharing is expected to continue its growth (Shaheen and Cohen 2012b).

2.6. Personal vehicle sharing

Shaheen et al. (2015a) define personal vehicle sharing (PVS) as a "carsharing service model characterized by short-term access to privately-owned vehicles. (…) PVS companies broker transactions among car owners and renters by providing the organizational resources needed to make the exchange possible, such as an online platform, customer support, automobile insurance, and vehicle technology." (emphasis added).

It has been argued that this segment is a "more pure manifestation of the sharing economy since it is based on the sharing of already owned, underused assets and not on the development of a company-owned fleet" (ITS America 2015). The commercial service offered is the matching of demand and supply by the PVS companies.

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[15] According to some estimates, they also need around twice as many reserved parking spaces as vehicles to function optimally (see Nakayama et al. 2002).

An important barrier to the development of this market segment is the important gap between potential demand and supply: "only about 25 percent of surveyed vehicle owners would be willing to rent out their vehicle, but (…) 60 percent of people without access to a car would be willing to rent a peer-to-peer vehicle" (ITS America 2015).

The main motivation for those who were willing to rent out their vehicles was economic, as this allows to spread the high acquisition cost over a higher customer base. Some argue that PVS could therefore support the growth of electric cars: "a Tesla Model S, which might lease for $900 a month, becomes affordable for many more people when it also produces $2,000 to $3,000 in that same period through Getaround rentals."[16] The low share of people who consider renting out their cars however suggests that these benefits currently do not outweigh drawbacks. Although we have not found an explicit discussion of this in the literature, one of the most important barriers is probably the establishment of a relation of trust. Especially in the upper segments of the market, owners are probably reluctant to rent out cars to strangers – and it is precisely in this market segment that the potential economic benefits of sharing are the highest.

However, as "frequent transit users were most open to renting through peer-to-peer carsharing, and people who drove frequently were less open to it", it has been argued that "peer-to-peer carsharing is likely to grow in dense, urban markets where car ownership is less prevalent and critical to the daily routine." (ITS America 2015). However, compared to traditional carsharing, it supposedly has more potential in suburbs and rural areas (ITS America 2015).

Shaheen et al.(2015a) distinguish 3 different following sub-models.

2.6.1. P2P Carsharing

Shaheen et al. (2015a) define P2P carsharing as a system that "employs privately-owned vehicles or low-speed modes made temporarily available for shared use by an individual or members of a P2P company." They argue that, compared to other carsharing services, P2P services appear to be more appealing to lower income groups[17].

2.6.2. Hybrid P2P-Traditional Carsharing and P2P Marketplace

Shaheen et al. (2015a) define hybrid P2P-traditional carsharing as a system "where individuals access vehicles or low-speed modes by joining an organization that maintains its own fleet, but it also includes private autos or low-speed modes throughout a network of locations", while "P2P marketplace enables direct exchanges among individuals via the Internet, including pricing agreements".

2.6.3. Fractional Ownership

Shaheen et al. (2015a) define "fractional ownership" as a model where "individuals sublease or subscribe to a vehicle owned by a third party. These individuals have 'rights' to the shared vehicle service in exchange for taking on a portion of the operating and maintenance expenses. This enables access to vehicles that individuals might otherwise be unable to afford, and it results in income sharing when the vehicle is rented to non-owners." In contrast to P2P carsharing, this model targets more expensive car models, which most households would not

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[16] http://knowledge.wharton.upenn.edu/article/how-green-is-the-sharing-economy/

[17] Although empirical evidence is limited to one study in Portland – Dill (2014), quoted in Shaheen et al. (2015a)

be able to afford. In the words of an industry executive, "Not only does it give the fractional owner flexible access to a fleet of vehicles, but it still allows the customer to invest in and identify with a single brand."18

As an example, Shaheen et al.(2015a) refer to the "Audi Unite" fractional ownership model launched by Audi in Stockholm in December 2014.

2.7. Characteristics of the supply side

Whereas carsharing becoming more widespread, both carmakers and traditional car hire firms have entered the market for carsharing services (Le Vine et al. 2014). Depending on the circumstances, they compete for the market or cooperate to deliver joint services.

Vehicle manufacturers face both specific challenges and clear advantages when entering this market (Le Vine et al. 2014):

- Carsharing is not part of their traditional core competencies and they need to "set up dedicated teams with the specialised skillsets as well as capital investments in information-technology systems".
- Compared to smaller independent operators, they enjoy "financial depth to bear risks such as residual values and to self-insure"
- The design and the integration of the necessary telematics equipment can take place in the factory, rather than as add-ons.
- They can mobilize general organizational resources. Le Vine et al. mention specifically: back-end IT systems, market research capabilities, brand recognition and optimal vehicle maintenance regimes.

For vehicle manufacturers, setting up car sharing schemes can also be a relatively risk-free way to explore the tastes of consumers in markets they are not familiar with. 19

Some authors (see for instance Burlando 2012) have argued that, because of the cost structure of carsharing, operators need to operate at a large scale, and this implies a higher level of concentration of the market to ensure its viability – for instance, in Germany, the 4 largest operators hold 65% of the market (defined as the number of users).

In the US, the "market is highly concentrated and the three largest operators have 87 percent of the total membership". 67% of the market is supplied by rental car companies, and around 25% by automakers (ITS America 2015).

In Europe, most car-sharing operators used to enjoy a "local monopoly". However, competition has increased over time, and "growing number of cities have more than one car-sharing operator active within its boundaries and there is competition amongst them" (Ciari et al. 2015). The use of travel apps could make competition more intense, both intra-modal and between modes.

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18 http://mashable.com/2016/05/30/car-ownership-autonomy-column/#2EGCip_p9qqo

19 http://www.psfk.com/2016/04/car-sharing-psa-group-peugeot-citroens.html

Whether such a concentration in the carsharing market would lead to monopoly power abuse, is a contentious matter. Burlando (2012) argues that operators would still need to compete with the other transport modes, and this would limit the potential for monopolistic practices. On the other hand, as pointed out by Le Vine et al. (2014), carsharing is not a perfect substitute for other forms of urban transport, and this limits the potential for intermodal competition. Le Vine et al. (2014) therefore ask that "policymakers do nothing to discourage competition between operators".

Recent work in the US (Schwartz 2016) suggests that carsharing companies tend to locate in areas with a high share of "typical" carsharing users (small households with few vehicles per household, but highly educated and with higher incomes). With the exception of firms operating in the P2P market, they also appear to concentrate on the downtown areas rather than the suburbs. All companies involved in carsharing operate mostly in large metropolitan areas (1 million inhabitants or more). It is not clear to what extent these observations are also valid for Europe.

2.8. Characteristics of the demand side

One of the more robust findings in the field of shared mobility is that, compared to the general population, users of **round-trip** carsharing service are (Le Vine et al. 2014):

- well-educated,
- young adults, predominantly between ages 25 and 45,
- living as single-person or childless-couple households,
- living in middle or middle/upper income households,
- living in carless or single-car households ,
- living in urban neighbourhoods,
- relatively heavy users of non-car forms of urban transport (e.g. public transport, walking and cycling).

The socio-economic profiles of the users of other types of carsharing appears to be broadly similar, but the evidence base is less reliable, especially in the case of P2P users (see Le Vine et al. (2014) and Kopp et al. (2015)).

The "young" profile of carsharing users is often referred to in concert with indications of a downward trend of car ownership and use amongst young adults, at least in some countries. However, Le Vine et al. (2014) emphasize that they "are unaware of unambiguous evidence showing shifts in young adults' consumption preferences relating to cars". Instead, they refer to structural changes in the constraints young adult face (such as the fallout from the financial crisis). Their key conclusion is that "researchers have yet to quantify the relative contribution of changing preferences as opposed to changing technologies and other external constraints". Note that this point will be a recurring theme in this report: if we really want to understand how new business models and technologies will change mobility demand, we need to dig deeper than what is usually done in current travel surveys, and understand better the fundamental motivations underlying travel behaviour, including modal choice.

2.9. The B2B market

Until now, our analysis has focused on the B2C market. A second market segment is business carsharing (or corporate carsharing), which can be defined as "a form of carsharing that enables commercial businesses to reduce or eliminate private vehicle fleets typically maintained for business purposes." (Shaheen and Stocker 2015)

Several variants are possible (Shaheen and Stocker 2015)

- The provision of exclusive-use vehicles to clients that are shared among employees and departments[20]
- The provision of shared vehicles where the client accesses the vehicles as part of a larger carsharing fleet (i.e., employees use the same vehicles that are shared by individuals and/or other business members)

Early examples of business carsharing date back to the Netherlands in 1995. The market has grown worldwide, and in a 2010 survey "the business market was reported to be the second most profitable, behind the neighbourhood roundtrip market at 54.5%." (Shaheen and Stocker 2015). According to Clark et al. (2015), "there is evidence that the B2B market segment is now growing faster than carsharing in general".

Some motivations for implementing business carsharing include (Shaheen and Stocker 2015, Clark et al. 2015; Le Vine et al. 2014):

- Operational advantages over previous fleet-based models,
- For carsharing operators, an important advantage is that B2B carsharing smoothens the temporal profile of overall carsharing utilisation during periods when the demand for personal use of carsharing services is low, and thus leads to higher fleet utilisation rates.
- Additional flexibility through increased mobility options;
- Effectiveness as a transportation demand management and parking management tool;
- Eliminates the high overhead and maintenance costs of a company vehicle fleet
- Reduces the need for staff to bring a car to work
- Employees have other mobility options for professional travel than their personal vehicle, which eliminates the need for complicated reimbursement and insurance arrangements; Actually, corporate carsharing eliminates a perverse incentive of car ownership, as an employee "may wish to drive their personal car for work-related travel, as in most instances they are compensated for their distance driven on an average-cost basis—meaning that each marginal mile driven helps to defray their fixed costs of personal car ownership".
- Employers may be motivated by notions of corporate social responsibility, or by external pressures such as the need to acquire permissions from a public body (e. g. planning permission).
- Providing a company's staff with access to a carsharing service for personal use (on top of business use) can be used as an employment benefit.

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[20] The difference between this variant and the traditional B2B lease market is not completely clear.

To date, empirical work on the B2B segments is very limited.

One exception is Clark et al. (2015), who have conducted a national survey in Britain. A central observation in the study is that "(a)pproximately one in seven (15 %) respondents indicated that their carsharing membership through their employer has changed their travel habits by allowing them to commute to work less often by private car (...). It appears that car use for (non-commuting) business purposes may increase, however." As the study is based on a dataset with a very low response rate (3 %), it is not clear to what extent its conclusions can be generalised to other contexts.

Shaheen and Stocker (2015) report that "(a)bout one fifth of corporate users surveyed claimed to have sold a vehicle and another fifth claimed to have postponed purchasing a vehicle due to joining Zipcar." However, the modal impacts are ambiguous; "members reported biking and taking public transit slightly less often and walking slightly more often". All in all, Shaheen and Stocker estimate that "there is a 13% induced demand effect (trips taken that would not have occurred, if Zipcar was not present)".

2.10. Assessing the impacts

The potential environmental advantages of carsharing operate through two channels (Firnkorn and Shaheen (2015)). First, fewer cars have to be produced to satisfy the same overall demand for automobility. Second, with carsharing, people use cars more selectively because the marginal costs loom larger than when they own their car (and the fixed costs thus dominate the marginal costs).

Unfortunately, empirical studies on the net impacts of carsharing face numerous challenges. Before proceeding with a discussion of the main results found in the literature, we shall discuss these methodological challenges.

2.10.1. Methodological issues

As pointed out by Shaheen et al.(2015a), when assessing the net impacts of carsharing, it is necessary to know:

- how individuals travelled before and what modal behaviours they changed due to carsharing and
- how individuals would have travelled in the absence of carsharing (e.g., postponed vehicle purchase).

Activity data alone cannot answer these questions, and surveys are required. An additional complication is that large (i.e. nationwide) surveys are typically unsuitable for the evaluation of shared mobility because (Shaheen et al.2015a):

- They do not reflect the dynamics of behavioural change before and after people start using the system;
- Within the overall sample, the sample of people using shared mobility services is typically small;
- There are important time lags between subsequent surveys; as a result, they cover different samples of the population.

Because of these limitations, Shaheen et al. (2015a) argue in favour of dedicated surveys of members of carsharing schemes. However, as we shall discuss in detail below, such dedicated surveys face problems of their own, such as self-selection of the sample.

Firnkorn and Shaheen (2015) discuss in detail two other fundamental methodological problems associated with the empirical assessment of carsharing schemes.

- The long term impacts of carsharing may be quite different from the immediate impacts, and the transition to a stable situation may take years. In the short term, carsharing may induce new travel as zero-car households start to drive carsharing-cars. In the longer run, households may shed their private cars, which can be expected to lead to a decrease in car usage[21].
- There are no agreed standards for the evaluation of carsharing-systems. As a result, "not a single study-design in the field of empirical carsharing research has ever been replicated". Moreover, most existing studies are static in nature.

There are at least three possible approaches to the evaluation of carsharing impacts:

- Studies measuring the **hypothetical impacts** ask carsharing users how they would hypothetically cover their mobility-needs today, if their currently used carsharing-system was not offered.
- Studies measuring **retrospective impacts** compare the mobility behaviour before and after people join carsharing-schemes.
- Studies measuring **future impacts** ask new carsharing-users for their planned future mobility-changes due to carsharing.

Firnkorn and Shaheen (2015) argue that the appropriateness of a method depends on the phase after a carsharing-system's launch:

> "For example, measuring a retrospective impact directly after the launch of a carsharing-system (when users have not yet adapted their mobility-behavior) would capture zero impact, as would asking for future impacts after carsharing-users have completely adapted their mobility-behavior (when no more changes will occur)."

Hence, they propose an approach that would distinguish between three phases after the launch of a carsharing system. For instance, the final stage, Phase C, corresponds to the long-term generational change in the user-base. As this new generation will lack a "before-carsharing"-state, retrospective-oriented impact-measurements would no longer be applicable.

According to Firnkorn and Shaheen (2015), recognizing the time- and method-dependency of carsharing impacts could improve policy-decisions. It would for instance avoid the termination of carsharing-system "because of an early static impact-snapshot not reflecting the long-term sustainability-gains that a city would achieve by keeping the carsharing-system". It would also avoid the use of the "before-and-after" evaluation-tradition used in the Western world in growth markets such as China, "where a growing number of middle class households will either purchase a first private car or alternatively stay private-car-free and selectively use carsharing (where offered)". Such a "before-and-after" evaluation-tradition could only find a VKT-increase through carsharing-systems, whilst a hypothetical impact study would find the opposite result.

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[21] See also the survey in Martin and Shaheen (2011).

Example: Adaptation process of the target parameter vehicle kilometers traveled (VKT) measured with a cross-sectional research design of the type *retrospective impact (1x DC)*
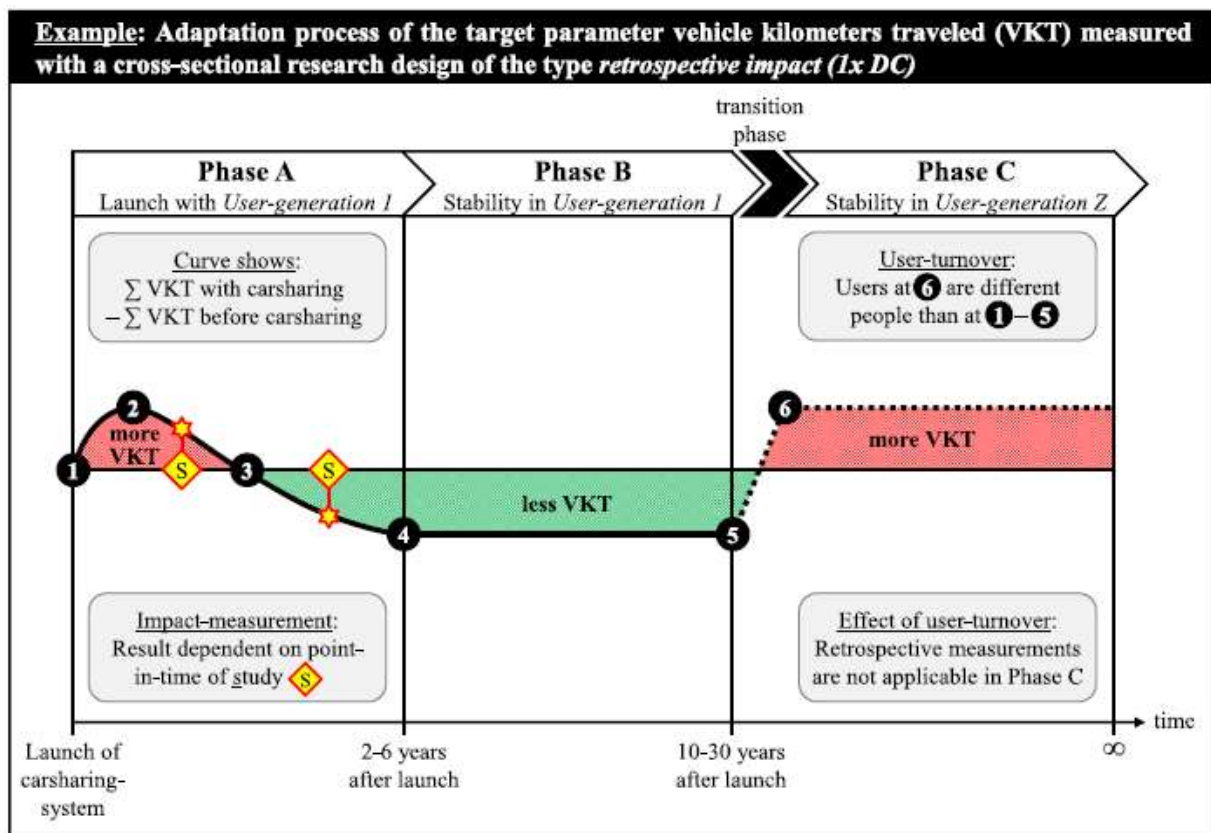
FIGURE 4: APPLICATION OF THE THREE-PHASE MODEL OF DYNAMIC ADAPTATION-PROCESSES (FROM FIRNKORN AND SHAHEEN 2015)

Mishra et al. (2015) and Kopp et al. (2015) point to another methodological issue: **self-selection bias.** Studies evaluating the impact of carsharing are likely to be plagued by this type of bias, for instance because "the adoption of carsharing is likely coupled with the decision to live in a dense, urban area, which in itself is known to have a significant impact on travel behaviour" (Mishra et al. 2015). Kopp et al. (2015) also find that users of floating car share systems "have better access to public transport in terms of distance and service level" while Martin and Shaheen (2011) observe that "carsharing members tend to have shorter commutes than most people living in the same zip code". All these are elements that would tend to be associated with lower levels of car use, whether or not the household would participate in a carsharing system. We have also pointed out above that suppliers tend to focus on areas with a high potential customer base.

Another important source of self-selection bias may be that households joining carsharing systems may simply have no access to private car ownership (for instance, for financial reasons). Finally, the decision to live in a dense area may itself reflect a deliberate decision to avoid a car-dependent lifestyle, which may reflect specific value systems that are not representative for the population at large.

Not correcting for these biases "may lead to overestimating the effect that carsharing would have on travel behavior if adopted by someone without those propensities, i.e. if policies promoting carsharing led to its adoption across a broader segment of society." (Mishra et al.

2015). In more general terms, it is likely that member of car-sharing schemes already displayed different travel behaviour as the average population before joining the scheme, and observed changes are therefore difficult to attribute (Kopp et al. 2015).

On top of these specific considerations, Le Vine et al. (2014) claim that "(t)here is a consensus that the impacts vary quite strongly between different carsharing service models. It is inappropriate, for instance, to apply the established impacts of round-trip carsharing to predict the prospective impacts of peer-to-peer and point-to-point carsharing systems." We will therefore treat the different variants of carsharing systems separately.

2.10.2. Round trip car sharing

The impact of **roundtrip** carsharing can be summarized as follows (Boyle and Associates 2016; Martin and Shaheen (2011), Shaheen et al.(2015a); ITS America (2015); Kockelman et al. (2016) ; Le Vine et al. (2014): Firnkorn and Shaheen (2015); Kopp et al. (2015); Shaheen and Cohen (2013); Fournier et al. (2015)):

- Several studies find that members of roundtrip carsharing organisations shed one or more personal cars (estimates range from 25% to 30%) or postpone the purchase of a personal car (estimates range from 25 to 66%).
- Depending on the study, it is estimated that a single carsharing vehicle replaces 3 to 13 vehicles among carsharing members. As we shall see further (see Section 10), the use of automated vehicles could reduce access time for shared vehicles and further increase the number of private vehicles that are replaced.
- Members have fewer cars per person in the household (0. 16 in comparison to 0. 55 for non-users).
- Thanks to the reduction in the number of cars, there is also a reduction in the need for parking space.
- Joining a roundtrip carsharing organisation is followed by reductions in Vehicle Miles Travelled (VMT) – depending on the study, estimate range from 27 to 80 %. The average *net* reduction in driving distance by round-trip carsharing users hides that carsharing leads to an *increase* in driving by some (e.g. people who otherwise would not own a car), which is however more than compensated by a decrease in driving by others (e.g. those who otherwise would be car owners). The decrease in driving by those who have moved away from car ownership could in part be due to the higher salience of the variable costs in the case of carsharing.
- The majority of households joining carsharing programs increase their GHG emissions by a small amount. This is however more than compensated by a much larger decrease in emissions by the households who emit less by shedding vehicles and driving less.
- Vehicles that are sold tend to be older and less fuel-efficient than vehicles in the carsharing fleet.
- Roundtrip carsharing is associated with an important increase in non-motorized modes and carpooling. The estimates of the impact on transit use are more mixed, and some studies even find decreases in the use of transit[22].

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[22] Martin and Shaheen (2011) have suggested that this decrease in public transit may be due to households who were carless before joining the carsharing scheme. They have also hypothesized that "carsharing and local transit are complementary, carsharing and regional transit may act as substitutes."

Although the results for North American carsharing organizations tend to be similar to the European studies, the details of the conclusions can vary widely, depending on the region and time period under evaluation (Martin and Shaheen (2011)). In general, it is difficult to compare results because methodologies vary. Moreover, the approaches used for data collection have often resulted in limited samples (Shaheen and Cohen 2013).

Keeping in mind the methodological challenges discussed in the previous sections, reported figures need thus to be interpreted with care.

In a recent study of carsharing in the San Francisco Area, Mishra et al. (2015) control for self-selection bias due to differences in observed characteristics of the respondents using propensity-score based matching23. They find that "vehicle holdings of carsharing members are substantially and significantly lower than for non-members with similar characteristics in terms of individual and household demographics and built environment features of both residential and job location. (…) Members are also likely to walk, bike, and use transit more frequently than non-members. However, these differences are relatively minor and tend to be statistically non-significant."

However, the authors acknowledge that they have not corrected for selection bias due to unobservable variables such as the attitudes of the decision makers. They argue that this bias may be small if the "unobservables are highly correlated with observed covariates" (for instance if "individuals with pro-bike and pro-walk attitudes are likely to live in urban neighbourhoods.").

Other limitations of the study are its cross-sectional nature and its failure to account for simultaneity or reverse causality bias (this refers to the possibility that people join carsharing schemes to get access to vehicles without having to buy one).

Again, we note that a real understanding of the mechanisms at work requires travel surveys that go in much more depth, and that aim at understanding fundamental motivations.

At the methodological level, the authors also argue in favour of the inclusion of shared-use mobility in future large-scale travel surveys.

It should be noted that most studies on the impacts of carsharing on car ownership report actual replacement rates of private cars, but do not attempt to model the maximum impacts that could be achieved. Morency et al. (2015) have undertaken a simulation study of the Greater Montreal Area in 2008. It is estimated that, in this region, "27 % of the owned cars are not used during a typical weekday". Moreover, international studies show that "a car will, on average, be parked more than 95 % of the time. " Simulation results show that, if the fleet in the region would be mutualized, "between 48 and 59 % of the current fleet of privately owned cars would be sufficient to fulfill all car driver trips at the metropolitan level." These estimates should be considered as indicative for the maximum potential. Indeed, the study does not consider the

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[23] According to Wikipedia, "propensity score matching (PSM) is a statistical matching technique that attempts to estimate the effect of a treatment, policy, or other intervention by accounting for the covariates that predict receiving the treatment. (…) For example, one may be interested to know the consequences of smoking or the consequences of going to university. The people 'treated' are simply those—the smokers, or the university graduates—who in the course of everyday life undergo whatever it is that is being studied by the researcher. (…) The treatment effect estimated by simply comparing a particular outcome—rate of cancer or life time earnings—between those who smoked and did not smoke or attended university and did not attend university would be biased by any factors that predict smoking or university attendance, respectively. PSM attempts to control for these differences to make the groups receiving treatment and not-treatment more comparable."

question which viable business model could lead to such results, and assumes that there are no behavioural or organizational barriers to such a full mutualization.

2.10.3. One way systems

The impacts of **one-way systems** have just recently begun to be studied. In a survey of the (sparse) literature on the issue, Shaheen et al. (2015b) find some evidence that some people would shed personal car ownership for membership of car2go and that participation could lead to reduced VMT. In an analysis of car2go in Ulm, Firnkorn (2012), investigated both the hypothetical impact and a retrospective impact. The result suggests a primacy effect (i.e. a "disproportionally high selection of first answer options") in the case of the first approach and an overestimation of the measured impact on distance travelled in the second approach: car2go users, who did not own a car before joining the scheme, walked less, cycled less and used less public transport after joining it.

Le Vine et al. (2014) refer to recent research in Paris showing that "both roundtrip and point-to-point carsharing encourage reductions in car ownership" but that the effect is more pronounced for round-trip carsharing – similar findings apply to the reductions in driving distance (-127 kilometres per user per month in the case of round-trip carsharing versus -43 kilometres per user per month point-to-point carsharing users).

Kopp et al. (2015) have found that free-floating carsharing users are both more multimodal (use of different forms of transport for different journeys) and intermodal (use of multiple forms of transport to complete a single multi-stage journey) compared to non-car-sharers. However, the "sharers" report more trips, but over smaller distances. In globo, Kopp et al. (2015) characterise the behaviour of the sharers as "more purpose-oriented and flexible": "They seem to actually choose the transport mode that best fits to their trips' specific requirements. The overall result is that free-floating car-sharers perform more trips with less traffic!"

However, as discussed above, endogeneity is an important problem in this type of retrospective comparison: it may well be that it is the multimodal and intermodal preferences of these users that have brought them to join the carsharing schemes in the first place. In the words of Kopp et al., they may represent "a target market of early adopters integrating free-floating car-sharing into their travel patterns." Therefore, the reported results may well overestimate the actual impacts of shared mobility.

Kopp et al. (2015) argue that through targeting services and their promotion to the group identified as ''low-hanging fruits'', one may induce significant multiplication effects on other person groups. Assessing the potential of such multiplication effects would require an explicit modelling of the impact of "social influences" on travel behaviour, as discussed in Chapter ***.

Compared to roundtrip systems, the need to reposition the vehicles does not only pose organisational issues, but could also reduce the benefits in terms of reduced distance travelled and emissions (ITS America 2015). We shall come back to this issue in our Chapter on automated vehicles.

2.10.4. Personal vehicle sharing systems

Evidence on the effect of personal vehicle sharing is very limited.

In a survey of British carsharing, Steer Davies Gleave (2015), interviewed 84 members of easyCar (the survey was only issued to vehicle-renters). A significant majority (69%) of the respondents

were not car owners before joining the scheme; the share of actual members owning a car is even smaller (20%). The majority of members responded that they were less likely to buy a car in the future. However, the share of respondents who would have bought a car in the counterfactual scenario of not joining the car club was also very low (around 15%). Moreover, "profile of car ownership amongst peer-to-peer members after joining a peer-to-peer car club is very similar to round-trip members." Contrary to the findings of the 2012 survey (discussed in Le Vine et al. 2014), P2P members on average reported reducing their annual car mileage travelled by 662 miles. This net effect results from a larger average decrease (by 3,538 miles) for the 15% who decreased their travel, than the average increase (by 1,119 miles) for the 25% who increased their travel. The contrast with the 2012 survey (which reported a net increase) confirms the point made in Firnkorn and Shaheen (2015): the effects of carsharing can only be evaluated over a longer period of time.

2.10.5. Shared electric mobility (and other alternative fuels)

Taking into account the potential environmental benefits of carsharing, one can ask whether encouraging the use of electric or hybrid vehicles in carsharing schemes could have a multiplier effect in terms of these environmental benefits. According to Le Vine et al. (2014), several operators include a limited number of electric vehicles in their fleet, and at least two operators (Autolib' in Paris, and car2go in Amsterdam) own a fleet with only electric powertrains. However, there is trade-off to take into consideration, as "electric vehicles are more complex to operate and overall less economic from the perspective of the carsharing service operator". (Le Vine et al. 2014)

On the other hand, with the current state of the technology, electric cars are probably better adapted for car sharing than for car ownership (Fournier et al. 2015). Indeed, with battery ranges varying between 100 and 200 km, they are adequate for most carsharing trips (which tend to be short term and inner city).

Moreover, carsharing operators could gain additional income from the provision of Vehicle-to-Grid (V2G) services - as explained by Fournier et al. 2015, V2G

> *"is the integration of electric vehicles into the electrical power grid to form a virtual power storage station. In a grid with a high proportion of renewable energy sources but fluctuating energy production, the load can be stabilised by the storage, feeding and charging of electricity from electric vehicles. It is possible e.g.: to use surplus power from renewable energy systems to substitute peak- loads."*

Fournier et al. 2015 also argue that the carsharing segment can serve as an advertisement for electric vehicles, as customers gain experience with the technology and range anxiety decreases. Here as well, there is a need for further research on the actual "social learning" process to understand how such propagation could take place.

One of the challenges to overcome is that the need for a charging infrastructure partly offsets one of the big advantages of carsharing: the reduced need for parking. This may lead to some resistance from city authorities.[24]

In an online survey of car2go-users in Ulm, Firnkorn and Müller (2015) have investigated whether offering electric cars in the scheme would affect the willingness to forgo a future car purchase. Their result indicated that the offer of electric cars does indeed affect this willingness, and

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[24] http://www.redherring.com/hardware/can-europes-blossoming-car-share-market-boost-electromobility/

that this effect is enhanced when the electricity is generated from 'regional' sources (rather than 'green' sources). Moreover, the "willingness to forgo" appeared to increase with previous experience in driving with shared electric cars – this is in line with the observation by Shaheen and Cohen 2013 that "carsharing users frequently report an increased environmental awareness after joining a carsharing program".

One example of a company that only rents electric vehicles is ServCo 1, which was founded in Norway in 2007. ServCo 1 serves only the B2B market segment, and lets its corporate customers pay for the fixed and variable costs of the charging infrastructure. For a monthly subscription and usage time fee, ServCo 1 takes charge of maintenance and charging demand management. Its services are offered through an online booking system (Weiller and Neely 2013).

Other alternative fuels than electricity are also in use. According to Shaheen and Cohen (2013), "(c)ompressed natural gas, ethanol, and other biofuels also have been deployed in the U.S., Brazil, and Sweden".

2.10.6. Dealing with endogeneity through population segmentation

We have already discussed the endogeneity problem that is intrinsic to innovative mobility solution such as car-sharing: those who chose to use such services may have value systems that differ from those of the "average" citizens, and the behavioural changes observed amongst early adopters may therefore not be representative for what is achievable at societal level.

Grischkat et al. (2014) have argued that services such as carsharing remain niche products, and that there are no consistent results regarding their net environmental effects. They argue that a "necessary condition to implement mobility services successfully and efficiently is sufficient knowledge about the potential user groups. The segmentation of the population into groups sharing similar attitudes and preferences provides valuable information about which segments are receptive of which services and how the services should be promoted in order to attract the respective user groups". Moreover, they point out that "(c)ompared to studies that group the population only by demographic, behavioural or spatial variables, segmentations that include attitudes provide better starting-points for interventions to reduce car use". This is consistent with the observation made above that spatial variables, for instance, may themselves be correlated with attitudes.

Grischkat et al. (2014) have performed a survey analysis, where respondents were asked explicitly to evaluate the "private car" not just on a functional, but also on a symbolic level (autonomy, excitement, status). Their central result was that

> "(a) metropolitan population between 18 and 80 years of age may contribute between 1 and 4% of transport-related GHG emission reduction by shifting to environment-friendly mobility services. When potential users were asked about their future use of certain mobility services, a further result was that some services, such as car-sharing, seem to have a much lower potential in the general population than is estimated in some scenario studies. Assuming that the trend of a 10% increase of participants in car-sharing schemes per year continues until 2050 (IEA/OECD, 2009) seems rather unrealistic according to our results, for example. In our sample car-sharing was predominately attractive for the mobility type that put least importance on symbolic-affective aspects of cars-use (…)".

This study also provides support for the hypothesis that "information and communication strategies for behavioural change can be addressed more effectively on the basis of

psychological variables than on that of spatial or sociodemographic characteristics". For instance, campaigns emphasizing the negative attributes of private cars may well be counterproductive when addressed to people who value the car for symbolic-emotional reasons. Other groups, however, may well respond to information concerning the environmental and safety implications of their mobility choices.

Although Grischkat et al. (2014) also acknowledge that "the increase of offered mobility services and shared use of transport vehicles like cars or bicycles in the population could lead to changes in the attitudes and values in the population", they emphasize the uncertainty regarding the magnitude of the rebound effects of technical and social innovations in mobility services, as these can result in a higher attractiveness of motorized modes, and thus also in their utilization.

2.11. Organisational and institutional issues

2.11.1. Approaches to 'rationing' the market

The most widely used approach to allocate road space in times of congestion is "rationing by queuing": roughly speaking, road space is allocated on a "first come, first served" basis, independently of an individual's value of time. The alternative (distance based charging differentiated according to the current levels of congestion) would imply "rationing by pricing", but is not applied widely25.

In carsharing systems, congestion can occur at the point of vehicle access. The current business practice is first-come/first-served (which is effectively "rationing by queuing") but "dynamic pricing" could be an option for the future (Le Vine et al. 2014).

2.11.2. Insurance

Insurance is one of the more complex issues associated with carsharing. Currently, the pricing of insurance schemes is relatively crude, and operator usually do not differentiate their prices among drivers. As a results, "insurance charges for carsharing services are typically 3-4 times what a comparable private car owner would pay" (Le Vine et al. 2014). However as operators accumulate evidence on their individual customers, risk assessments will improve, and these can be used to improve pricing practices and providing incentives for safer driving (Le Vine et al. 2014).

2.11.3. New business models

It is possible for carsharing operators to develop partnerships that could expand their earning model.

One possibility would be to get paid for acting as a "safety valve" when high traffic volumes can be anticipated (for instance, due to major events): in such cases, "the road network manager could simply block-book some or all of a carsharing system's fleet, in effect paying the private sector operator to keep their vehicles parked during some period of time." (Le Vine

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25 Where road charging is used, it is either not strictly distance based (see for instance the congestion charges in London and Stockholm), or limited to specific categories of vehicles and roads (heavy duty vehicles on highways in Germany and Belgium, for instance).

et al. 2014) A drawback of such a system is that it would reduce the reliability of carsharing from the users' point of view.

Operators could also set up partnerships with retailers. One real world example reported by Le Vine et al. (2014) comes from Germany, where a discount card stored in the shared car can be used in designated shops. Taking into account that shared cars are often used precisely with "shopping" as trip purpose, such partnerships could well expand in the future.

Another example is a carsharing scheme that the Co-wheels Car Club has set up with the Cumbria County Council, The Lake District National Park Authority and Cumbria Tourism. The scheme offers two-person electric vehicles, Renault Twizys. These vehicles are agile, compact and light weight, and offer tourists to visit the Lake District, supposedly with a minimal impact on the local environment26. Of course, this is a typical example of a niche application, but the Twizys are also used in the segment of urban mobility – see the Section 3.

2.11.4. Carsharing and public policy

We have already discussed above that there is evidence that carsharing can contribute to the realisation of outcomes that are desirable from the public perspective (less pollution and congestion, for instance). One subtle point in this respect is that the time-based pricing model of carsharing is actually a form of congestion pricing, as users who drive during the peak hours (and thus experience longer travel times) will have to pay more (Le Vine et al. 2014). Thus, a wider use of carsharing would in effect "privatise" time- and place-differentiated road pricing, which (despite some successful implementations) remains politically unpalatable.

On the other hand, carsharing often requires active support measures from public authorities (such as making parking space available in the case of "one way" systems). Compared to the support that is required for public transit or for the construction of new infrastructure, this type of measures can easily be reversed if necessary (Le Vine et al. 2014), or if evidence shows that the schemes does not lead to the desired outcomes.

On top of the "direct" support provided to carsharing schemes, government could also promote the modes that "complement" car sharing, such as walking and cycling. Expanding "investments in pedestrian and bicycling infrastructure can serve to support an environment in which carsharing becomes more viable for people who otherwise rely more heavily on their personal vehicles" (Martin and Shaheen 2011). Similar considerations apply to the need to integrate "carsharing with other shared-use mobility modes and with transit" as a tool to increase "the scale and connectivity needed to make carsharing a real option for a broader population." (ITS America 2015).

National governments could also provide support by giving their staff access to carsharing, by sponsoring demonstration projects and providing policy guidance.

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[26] http://intelligentmobilityinsight.com/news/Cqr

3. Scooter sharing

Shaheen et al. (2015a) refer to the existence of several scooter sharing systems in Europe and two in the United States, all of which offer one-way and roundtrip short-term scooter sharing, including insurance and helmets. Some also offer electric motorcycle sharing and Scoot Quads (two- seater "Twizy" vehicles from Renault, branded as Nissan in the United States).

4. Bicycle sharing

4.1. Definitions

Shaheen et al. (2015) define bikesharing as systems which "allow users to access bicycles on an as-needed basis from a network of stations, which are typically concentrated in urban areas. Bikesharing stations are usually unattended and accessible at all hours, granting an on-demand mobility option. In these systems, the operators are typically responsible for bicycle maintenance, storage, and parking costs."

Shaheen et al. (2015) further distinguish between the following types of bikesharing systems:

- Public bikesharing. This refers to schemes where anyone is able to access a bicycle for a nominal fee (with a credit/debit card on file).
- Closed campus bikesharing. These are deployed at university and office campuses, and they are only available to the particular campus community they serve.
- P2P bikesharing: These are available in urban areas for bike owners to rent out their idle bikes for others to use.

4.2. History

The first documented "bikeshare" system was launched in Amsterdam in 1964. In this system, white painted bicycles were available in the street, and people could use them freely. In the absence of any payment or security function, the system was vulnerable to theft and vandalism, and was quickly abandoned. The second generation of bikesharing system was initiated in Copenhagen in 1995 and used a coin deposit system. This system remained vulnerable to theft. Other systems required identification for bicycle access. Some of these schemes are still in use in North America. The third generation of bikesharing system used dedicated docking stations, automated credit card payment and other technologies to track the bicycles. These systems did get off the ground. So-called fourth generation systems include dockless systems[27], easier installation, and innovative systems for bicycle redistribution, GPS tracking, touchscreen kiosks, electric bikes and transit smartcard integration (Fishman 2016 and Martin and Shaheen 2014).

According to Fishman (2016), the current global bikeshare fleet is estimated at 946 000 bicycles, of which 750 500 are in China.

According to Marsden et al. (2015), as of 2014, there were 414 bikeshare programs in Europe, compared to 50 in North America. The Velib' scheme in Paris is the second largest in the world,

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[27] In such systems, "the entry and checkout function is packed into a small computer terminal on board each bike, rather than at fixed system-branded racks (i.e., docks)." In order to provide incentives to use the conventional public docking stations (and thus decrease the logistical costs of the system), the operator can still impose a small financial penalty on customers who lock up elsewhere –for an example, see http://urbanland.uli.org/economy-markets-trends/bike-sharing-pedals-toward-fourth-global-generation/

with approximately 20,400 bicycles, more than 100,000 rentals per day and more than 200,000 registered users.

As was the case of carsharing, these numbers, while impressive, need to be put in perspective. For instance, even if we limit the definition of Paris to its municipal boundaries (rather than the metropolitan area), the city has more than 2 million inhabitants. Thus, the number of rentals per day is at the very most 1 per 20 inhabitants[28]. We are not aware of studies assessing the potential for future growth from current levels.

Most existing schemes are not financially self-supporting. Some are operated in the framework of a public-private partnerships (for instance, with an advertising company), while other require some support from non-profit organisations, public transport operators or local governments[29].

An important limitation of the existing literature is that, to the best of our knowledge, there are no assessments of the cost-effectiveness of existing schemes, i.e. whether some approaches are capable of providing the same service levels as others, but at a lower cost.

4.3. Usage

Despite important differences between individual bikesharing programs, there are also important common elements (Fishman 2016):

- Weekday usage peaks between 7 am–9 am and 4 pm–6 pm, while weekend usage is strongest in the middle of the day.
- Demand for bikesharing is higher in the warmer months.
- Casual users typically take longer trips than annual members and trips are longer during warmer months.

As regards the motivation for using shared bicycles, research has found that: (Fishman 2016):

- Convenience is the major perceived benefit.
- Proximity between work and the closest docking station has been identified as the second strongest motivator, but having a docking station close to home is also important.
- Financial savings are also a motivating factor, especially for low income members (although the importance of this factor is more variable).

Contrary to what one may expect, most members turn out to be infrequent users – in several surveys in different countries, almost half of the respondents had not used the service in the previous day, and in one survey, only around 14% of the respondents used the system on a daily basis. This indicates that most members do not use shared bikes as primary or even secondary transport mode, but at the most as an occasional complement (Fishman 2016)

The trip purpose reported by the user can be affected by the day when the survey is taken, but it seems that casual users' main motivation is "leisure or sightseeing", while long-term users are more likely to use the shared bike for work trips (Fishman 2016).

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[28] We need to keep in mind that users will typically rent a bicycle in both directions of their trip and that tourists can also obtain short term access to the scheme.

[29] http://www.civitas.eu/content/civitas-insight-10-bike-sharing-link-desired-destinations

4.4. User socio-demographic profiles

Compared to the general population, users tend to be of higher average income and education status. Compared to regular bicycle users, sharers are more likely to be younger, own fewer cars and bicycles and to have lower mean household incomes (although regular cyclists may themselves have higher than average incomes). Most users of bikesharing schemes do not own bicycles. They are also more likely to live and work in the inner city. One must however be careful in the interpretation of these results, which are based on a limited number of surveys (Fishman 2016). Martin and Shaheen (2014) have pointed to the similarities in profile between bikeshare users and carsharing members.

As already discussed in the case of carsharing, self-selection bias may play a role in bikesharing as well, as "it may be where bicycles are placed rather than the type of people attracted to bikeshare that is the motivating factor for use"(Marsden et al. 2015).

4.5. Barriers

Very little data are available on the profiles of those who do not use bikesharing, and therefore, there is also a paucity of evidence regarding to the barriers to using bikeshare systems. For instance, a low level of bikesharing in a given area may reflect that (a) existing levels of bicycle ownership are already high30 (b) for most destinations, a unimodal trip with one's own bicycle may be more convenient than a multimodal trip with public transport and shared bicycles (for the first and/or last mile).

Based on the evidence that is available, the following elements appear to be important (Fishman 2016):

- Non-users find driving too convenient.
- The absence of docking stations close to the respondents' homes.
- Safety concerns when cyclists have to drive in traffic.
- If there is no immediate access to helmets at the point of departure, mandatory helmet legislation can be an important barrier.
- The sign-up process can be a barrier. However, with third-generation systems, where prospective users can sign up on the spot, with a credit card, this is less of an issue.

4.6. Impacts

Fishman 2016 points out that "many of the benefits associated with bikeshare" are based implicitly on "an assumption that bikeshare is used to replace trips previously made by car". However, although bikeshare does indeed appear to reduce car and taxi use, most of the modal

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[30] The high levels of vehicle ownership amongst city residents was a major reason why a first attempt to introduce bikesharing in the Dutch city of Utrecht was suspended http://www.civitas.eu/content/civitas-insight-10-bike-sharing-link-desired-destinations

shift is away from trips made by public transport and walking, although there are also examples of increases in the use of public transit (Martin and Shaheen 2014).

Martin and Shaheen (2014) explain the inconsistent reported effects on public transit use as follows:

> *"As bikesharing systems position bicycles in locations throughout the city, new opportunities emerge to complete first-and-last mile connections to public transit networks that were not previously possible. At the same time, bikesharing also provides opportunities to move faster than public transit systems, particularly within the dense networks present in downtown areas. (…) shifts away from public transit are most prominent in core urban environments with high population density. Shifts toward public transit in response to bikesharing appear most prevalent in lower density regions on the urban periphery (…) If this dynamic holds across multiple cities, public bikesharing may be more complementary to public transit in small to mid-size cities and more substitutive of public transit in larger and denser cities (perhaps alleviating crowded transit lines during peak periods)."*

Marsden et al. (2015) conclude that, just as with car sharing, bike share schemes appear to "contribute to modest reductions in car mileage by offering an alternative to car ownership either entirely or for second cars, or by making multi-modal trips more attractive and feasible."

Whether the shift away from public transport is a good or a bad thing (beyond the time and monetary savings for the users of the bikeshare scheme) is probably highly situation specific. For instance, if public transport is overcrowded during peak hours, this shift may improve the travel comfort for other passengers. However, if the move is away from services that are marginally financially viable, then this move could well lead to the shutdown of services, and a shift from the remaining passengers to private car mobility (or to the disappearance of the only mobility option that was available to some categories of passengers).

To the best of our knowledge, there are no quantitative assessments of avoided emissions following the introduction of bikesharing system. An important complication is that one should not just consider only the avoided emissions due to the displaced trips per motorized mode, but also the emissions caused by the repositioning bicycle over the day – we discuss this in more detail below. Tellingly, Fishman (2016) considers the assessment of the effects on emissions to be one of the priority areas for further research.

Moreover, bikesharing may bring other benefits to the users than the obvious ones.

In a study on the health impacts of the bicycle sharing system in London, Woodcock et al. (2014) have estimated the "(c)hange in lifelong disability adjusted life years (DALYs) based on one year impacts on incidence of disease and injury, modelled through medium term changes in physical activity, road traffic injuries, and exposure to air pollution." Their main conclusion was that "London's bicycle sharing system has positive health impacts overall, but these benefits are clearer for men than for women and for older users than for younger users. The potential benefits of cycling may not currently apply to all groups in all settings." The findings of other studies confirm that the actual benefits depend on which travel mode is replaced by bikesharing (Fishman 2016).

Concerning the specific issue of traffic safety, "the levels of serious injury and fatality have been lower than many predicted (…) and some evidence has now emerged to suggest that

bikeshare may even be safer than riding private bikes, although the precise mechanisms leading to such an effect require further research." (Fishman 2016). One possible explanation is the "safety in numbers phenomenon", which would then be an external benefit of bikesharing. However, this remains speculative. Other reasons include the design of the bicycles used in shared systems, more cautious behaviour by bikesharing users compared to other cyclists and the public infrastructure improvements that usually go hand in hand with the introduction of bikesharing systems (see Martin et al. 2016).

4.7. Logistics

One of the challenges facing bikeshare systems is that, over the day, the distribution of bicycles over docking stations may become unbalanced. Several authors have studied how station activity can be affected by factors such as the weather, the presence of restaurants, and the topography of the city (Fishman 2016).

The need to rebalance docking stations by dedicated trucks or vans can reduce the environmental and congestion benefits of the system (although we are not aware of studies quantifying these effects). Therefore, some authors have investigated the possibility to provide users with price incentives to redistribute bikes. However, during weekdays, the potential for this type of incentives remains limited (Fishman 2016). Fishman (2016) concludes his survey of this topics by the remark that behavioural economics "enhance incentive opportunities for users to redistribute bicycles against typical tidal flows".

While the issue of logistics is an important challenge, it is also an example of a complex problem that has been reduce to manageable proportions thanks to recent developments in ICT. State-of-the-art bikesharing systems record in real team how many cycles and docks are available in each station. These data can be used for (Romanillos et al. 2016):

- The identification of spatial-temporal patterns, relating the use of different stations to clusters of activity during a weekday
- The development of predictive models to forecast cycle demand

This information can be useful, both for users and for the operators of the system.

4.8. Perspectives

Fishman (2016) concludes his very recent review of the literature by some considerations on further directions for practice and research:

- Installing GPS on shared bicycles may reduce the need for physical docking stations, and may help operators in the "task of re-distributing bicycles across their fleet via the use of real-time tracking". The data provided by the GPS may also be useful for general transport planning purposes.
- E-bikeshare could expand the market to new segments of the population, and reduce the barriers linked to trip length and excessive heat. Moreover, because they reduce

the difficulties caused by a city's topography; e-bikes can also reduce the problems related to re-balancing in hilly cities.
- Fishman argues that optimising fleet-rebalancing, applying behavioural economics to change behaviour and a better understanding of the profile of non-users are high on the list of future research needs. He also points to the absence of standard methodology to measure the impacts of bikeshare "in terms of climate change, congestion, air and noise quality, as well as health and time savings"
- Finally, existing research activity does not reflect the huge share of the Chinese market.

Taking into account its low price (when compared to ownership), bike sharing could also help in the fight against "mobility poverty". However, the requirement to pay with credit card could be a major impediment for the population segments that suffer most from "mobility poverty". Moving back to cash payments could lower the barriers for those social groups31.

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[31] http://urbanland.uli.org/economy-markets-trends/bike-sharing-pedals-toward-fourth-global-generation/

5. On-demand ride services

On-demand ride services are the quintessential example of transport services that have not just been facilitated by mobile apps, but that would probably would never have existed without them. Arguably, this type of services was initiated by Uber in 2009, and it has been in the spotlight ever since, not just because of innovative nature of the services offered, but also because of the controversies that some of the new business practices have stirred. It is therefore important to understand the distinctive features of these services.

Shaheen et al. (2015a) actually distinguish three types of on-demand ride services: ridesourcing or transportation network companies (TNCs), ridesplitting within these TNC services, and e-Hail services for taxis with medallions. We will maintain this classification below. However, we will first sketch the main characteristics of the traditional taxi markets, to which they are seen as the closest competitors.

Note that, while popular media sometimes use the term "carsharing" to describe this type of service32, we will maintain the convention in the scientific literature to use "carsharing" only in its more restrictive sense (see Section 2).

5.1. The traditional taxi market

The taxi market is very heterogeneous, and, depending on the country or even the city, the market segment that is being referred to as the "taxi" market can actually have quite different meanings.

The following market definition corresponds to the way the services are offered (see for instance Aquilina (2011); Salanova et al. (2011); Rayle et al. (2016))

- **Street and rank hiring.** This refers to taxi services provided through random picking for hire on the streets ('hailing') or through a 'first in, first out' allocation system at taxi ranks. Due to the nature of the allocation system, consumers are usually not in a position to compare different possible offers before choosing a taxi. Therefore, competition in this market is limited or non-existent. As a result, consumers have no bargaining power as regards the price, and taxi drivers face no incentives to improve the quality of their services. In the sub segment of the 'hail' market, an additional problem is that a lot of empty taxis cruise the streets looking for passengers, adding to congestion and air pollution, and possibly affecting traffic safety as well. Moreover, in the absence of regulation, the barriers to entry in the market are low. There is a risk that drivers will try to increase their profits through unsafe driving behaviour and the neglect of maintenance.
- **Pre-booking segment**. This refers to "any other forms of provision of services such as telephone or Internet booking". In this segment, consumers can shop around before booking, which increases not only competition on price, but also provides incentives for investing in brand reputation.

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32 See the discussion in Le Vine et al. (2014).

This classification does not apply to all local situations. For instance, in some cities, large companies operate in both market segments, and taxis cruising on the streets can be directed to patrons through the central booking system. We shall see below that the possibility of booking taxis through the Internet or mobile apps is increasingly blurring the line between the two market segments.

In cities where the two markets are clearly delimitated, the first market segment is often subject to some type of regulation (maximum prices, limited entry) to compensate for the lack of effective competition and the externalities caused by the search for clients. However, the pre-booking segment usually is not regulated beyond standard safety requirements.

However, where restrictions exist in the second market segment, the impacts on entry can be dramatic. For instance, in 2014, there were 17,600 licensed taxis but just a few thousand minicabs in the Paris region (compared with 22,000 black cabs and 50,000 minicabs in London)[33],[34]

The approaches used to restrict entry to the market include: the requirement to obtain an occupational license, the prohibition to pick up passengers outside of the jurisdiction that issued the license or the limitation of the number of taxi drivers by the number of medallions that are issued (Cramer and Krueger 2015).

The regulation of taxi markets is the subject of a vast literature. Several authors have argued that restricting access to the market (for instance, through a 'medallion' system) only further reduces competition, and creates monopoly rents for the medallion owners. For instance, in a recent analysis of the New York taxicab market, Çetin and Eryigit 2013 conclude that "regulation brings about artificial rents by increasing medallion prices, and an increase in medallion prices gives rises to upward pressure on taxi fares". Note that the medallion owners are not always the taxi drivers, and thus that entry restrictions do not necessarily benefit the taxi drivers themselves (Salanova et al. (2011)).

Moreover, with fixed prices, if drivers are faced with a falling demand, they have an incentive to move from the 'hailing' sub segment to the 'rank' sub segment, which leads to a further fall in the quality of service (Salanova et al. (2011)).

On the other hand, it is acknowledged that taxis offer some advantages compared to mass transit, such as "speediness, door-to-door attribute, privacy, comfort, long-time operation and lack of parking fees" (Salanova et al. 2011). Salanova et al. (2011) argue that real issues, such as safety and quality regulation and possible abuses at high-demand generation points (such as airports, train stations or hotels), need to tackled with dedicated regulatory instruments rather than with general quantitative restrictions on market access.

The taxi market can be considered as "gap filling" mode, which provides transportation when neither private cars nor public transit are realistic or attractive options (for instance, for older citizens or lower- income groups who do not own a car). Therefore, taxis can be both substitutes

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[33] http://www.economist.com/news/europe/21596575-case-study-vested-interests-trying-fight-new-competitors-taxi-wars

[34] At the time of writing, the European Commission was preparing to challenge a French law which "requires chauffeured cars to return to a base between fares, restricts their use of software to find customers in the street and banned unlicensed services, among other measures". http://www.reuters.com/article/us-eu-uber-tech-france-idUSKCN0XG0Z0

and complements to collective travel modes (for instance, to fill the "last mile") (see Rayle et al. 2016 for a more extensive discussion).

5.2. Ridesourcing/Transportation Network Company (TNC) Services

This category refers to services that "use smartphone apps to connect community drivers with passengers" (Shaheen et al. 2015a). These services are variously referred to as ridesourcing, TNCs, ride- hailing, and ride-booking, with companies such as Sidecar[35], Lyft and uberX as most renowned examples. A new service, Juno, is about to launch in New York in spring 2016[36]. In China, Didi Chuxing (formerly Didi Kuaidi) is the most important player[37].

The booking process can be described as follows (Rayle et al. 2016):

"Ridesourcing allows travellers to request a ride in real-time through a smartphone application, which communicates the passenger's location to nearby drivers. After a driver accepts a ride request, the passenger can view the vehicle's real-time location and estimated arrival time. The app provides GPS-enabled navigation, which helps non-professional drivers find destinations and reduces the chances of them taking a circuitous route. The payment—and sometimes tips—are automatically charged to the passenger's credit card. The driver keeps a portion of the fare, with the balance going to the ridesourcing company. (…) Drivers and passengers rate each other at the ride's completion, creating an incentive system that rewards polite behavior. Unlike taxis, ridesourcing services like uberX, Lyft and Sidecar typically use drivers who lack a commercial vehicle license, drive their personal vehicle, and work part-time."

In March 2016, a new start-up, Arcade City launched its services in more than hundred cities in the US and Australia, and plans to expand quickly to Mexico, Canada and Sweden. Compared to the "older" TNCs, important differences in Arcade City's business model are that it allows riders to review the riders in advance and to select the preferred driver themselves and that drivers are allowed to set their own rates. Moreover drivers are allowed to offer additional services such as deliveries. Thus, the new services "delegates" decisions to the rider and the drivers that are managed automatically and centrally in the case of the 'established' TNCs38 The Israeli

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[35] Sidecar shut down in December 2015. Its assets and intellectual property have been taken over by General Motors – see https://en.wikipedia.org/wiki/Sidecar_(company)

[36] http://fortune.com/2016/03/28/juno-ridesharing-uber/ At the time of writing, the main difference in the business model of Juno compared to the existing TNCs; appears to lie in labour arrangement: Juno would take a lower commission on individuals rides and offer drivers equity in the company. More importantly, drivers who work exclusively for Juno would be eligible for a status as full-time employee – only those would work for several TNCs would be contractors.

[37] http://www.reuters.com/article/us-didi-kuaidi-china-merchants-bank-idUSKCN0V50YQ

[38] http://finance.yahoo.com/news/ridesharing-startup-arcade-city-launches-120000535.html

start-up Gett provides similar services, but only with taxis and black cars. Moreover, it does not use surge pricing39.

Although most attention goes to ridesourcing with cars, there is nothing that prevents the basic concepts to be applied to motorcycle taxi services, such as is indeed the case in Kigali (Rwanda)40 . In Pakistan, ridesourcing with rickshaws is also being tried – due to still low smartphone penetration, SMS messaging is used instead, and localisation of drivers is based on cellphone towers41. Also, while the payment by credit card is considered to be an essential component of the TNCs' business model, Uber accepts cash payments for its operations in Africa[42].Both Lyft and Uber have now started introducing scheduled rides as well[43].

TNCs have experienced a spectacular growth over the last few years. For instance, in April 2015, Uber operated in 301 cities in 57 countries (ITS America 2015). Their success is attributed to a large extent to the "efficiency and reliability of the matching platform and pricing mechanisms, along with the accountability of the rating system" (Rayle et al. 2016).

An important difference with ridesharing (see Section 6) is that "ridesourcing drivers operate for-profit and typically provide rides not incidental to their own trips" (Rayle et al. 2016).

Another important characteristic of these services, which differentiates them from the traditional taxicab market, is the use of dynamic pricing or "surge pricing": during periods of peak demand, prices increase to balance supply and demand. In concrete terms, the purpose of "surge pricing" is to provide incentives to drivers to accept drive requests when demand increases, for instance due to poor weather (Shaheen et al. 2015a). Whilst "surge pricing" is, strictly speaking, a simple move from "rationing through queuing" to "rationing through prices", it has turned out to be one of the more controversial aspect of the TNCs' business models (reference needed)44.

The impact of the competition from TNCs on the traditional taxi market varies according to local circumstances. In some cities, such as San Francisco and Los Angeles, the number of trips taken per taxi has decreased by 30 to 66%. In business models where taxi drivers are independent contractors who pay fixed fees to rent the vehicles from the companies owning the taxis, the financial consequences for the drivers can be dramatic45.

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[39]http://www.forbes.com/sites/scottbeyer/2015/10/15/dont-like-rideshare-surge-pricing-go-with-gett/#38f4ca4df3b8

[40]http://www.economist.com/news/middle-east-and-africa/21697278-potential-and-pitfalls-african-tech-innovation-africa-uber-alles

[41]http://www.nytimes.com/reuters/2016/06/19/technology/19reuters-pakistan-transport-apps.html?partner=IFTTT&_r=0

[42] http://www.thedrive.com/news/3689/uber-is-testing-cash-payments-and-image-based-navigation-in-africa

[43]http://gizmodo.com/soon-youll-be-able-to-schedule-uber-rides-1781741235?utm_medium=sharefromsite&utm_source=Gizmodo_twitter

[44] Rumours that Uber is considering ending "surge prices" are as yet not confirmed http://www.npr.org/sections/alltechconsidered/2016/05/03/476513775/uber-plans-to-kill-surge-pricing-though-drivers-say-it-makes-job-worth-it

[45] http://www.latimes.com/local/lanow/la-me-ln-uber-lyft-taxis-la-20160413-story.html

Some of these companies also provide specialized services (such as Lift Hero for disabled people and senior citizens,). At the time of the writing of the survey by Shaheen et al. (2015a), these specialised services were not yet provided outside California. Lyft's Shuddle programme to drive children to or from school has shut down in April 2016, apparently because it could not find the necessary funding for the continuation of its activities46.

Whilst TNCs have proved formidable competitors for traditional taxi services, it is far from certain that their business model is unassailable. Key features, including the matching app, can be replicated by competitors, and this is exactly what is currently happening47. For instance, we have already mentioned that BMW is now experimenting with a new system of one way carsharing, ReachNow, which would allow customers to ask for a car with driver. In this business model, the driver could be a student who would offer services when the demand for 'traditional' carsharing is low. This type of service would directly compete with the business model of TNCs48.

Another example of a traditional car manufacturer who is (indirectly) entering the market is General Motor, who has partnered up with Lyft in the Express Drive program. In this system, Lyft drivers can rent a car from GM to perform their services. If the driver performs 40 rides in a week, the mileage is free, and if the weekly drives exceed 65, then the fixed weekly fees are also waived. Lyft is said to see this as a step to lure drivers away from Uber, by giving them the possibility to provide ridesourcing services without owning a car (or owning a car that meets minimal standards)49. Volkswagen has invested 300 million USD in Gett, with as main ambition to "offering on-demand rides to the B2B market"50.

Other major car manufacturers such as Jaguar Land Rover51 and Ford52 are also making moves in this direction, even though the scope of their strategic repositioning seems to be broader53.

As we shall see below, the 'traditional' taxicab market is also increasingly using mobile apps.

Whilst TNCs are increasingly facing competition from "traditional" industries (or are entering into partnerships with them), they are also entering markets that go beyond the provision of mobility services. For instance, Uber offers app developers to add a button to their app which would allow users to request an Uber drive to drive them to a destination that the button is linked to54. For instance, users who have chosen a restaurant with a dedicated app could use this app to book a ride to that restaurant. The direct effect of such a feature is to make it

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46   http://techcrunch.com/2016/04/14/shuddle-the-uber-like-service-for-getting-your-kids-around-is-shutting-down-tomorrow/

47 http://www.bloomberg.com/gadfly/articles/2016-03-14/bmw-ride-sharing-plan-is-aimed-at-uber-threat

48 http://www.bloomberg.com/gadfly/articles/2016-03-14/bmw-ride-sharing-plan-is-aimed-at-uber-threat

49 http://www.industryweek.com/emerging-technologies/uber-challenge-gm-rent-cars-lyft-drivers

50 http://fortune.com/2016/05/24/volkswagen-gett-investment/?xid=smartnews

51 http://www.theverge.com/2016/4/11/11405944/jaguar-land-rover-inmotion-car-sharing

52 http://www.theverge.com/2016/3/11/11201870/ford-smart-mobility-llc-ride-share-car-share-self-driving

53 For instance, in the case of Ford, they even extend to e-bikes.

54 http://www.theverge.com/transportation/2015/12/2/9835604/uber-button-app-developer-API-rideshare

easier to call an Uber driver, but is also likely to provide Uber with information on the restaurant55.

5.3. Ridesplitting within TNC services

Shaheen et al. (2015a) define "ridesplitting" as "splitting a ridesourcing/TNC-provided ride with someone else taking a similar route. (…) These shared services allow for dynamic changing of routes as passengers request pickups in real time." Shaheen et al. (2015a) refer to Lyft Line and UberPOOL as providers of such services. In both cases, users are provided with monetary incentives to congregate at designated intersections or major arterial streets. According to Greenblatt and Shaheen (2015), this service "is reported to be approximately 50 % of the ridesourcing market in the Bay Area".

5.4. E-Hail Services for regulated taxis

According to Shaheen et al. (2015a), this type of service should be understood as a reaction from the taxi industry in the face of the rise in ridesourcing/TNCs. As taxis can be "e-hailed" through the Internet or by mobile apps, waiting times for taxis have been brought in line with those of ridesourcing/TNCs. These services can be maintained either by the taxi companies themselves or by external providers. An important difference with ridesourcing/TNCs, is that the rates of such services remain subject to regulations (if applicable) and that (up to now) they do not practice "surge pricing".

For instance, in 2010, Hailo was founded in London and has rapidly expanded worldwide. "Wherever it goes, Hailo works only with taxis that may be hailed in the street. It starts by signing up cabbies, who have their own app on which they can record journeys and fares, and which alerts them to "bursts" of demand (as people leave a concert, say). The app for passengers comes later (…) Cabbies will earn points for accepting "e-hails" when demand is at its peak and work is easy to find on the street; the highest scorers will have priority when work is scarce." 56. Note that, although this incentive scheme is not literally "surge pricing", its fundamental design is similar.

It is also noteworthy that Uber has also set up a cab service in a few cities, uberTAXI57 - thus, the distinction between "pure" taxicab services and "pure" TNCs is not clear-cut, as both 'sides' are taking initiative that increasingly blur the line between the two.

In order to promote the use of smartphone technology in the taxicab sector, the International Road Union, has set up the UpTop global taxi network, a partnership of taxi industry federations

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55 http://fortune.com/2016/05/25/uber-foursquare-deal/

56http://www.economist.com/news/business/21588101-ever-more-cities-smartphone-apps-are-reshaping-taxi-market-tap-hail

57http://www.economist.com/news/business/21588101-ever-more-cities-smartphone-apps-are-reshaping-taxi-market-tap-hail

and taxi app providers. 17 partner apps and 500,000 taxis have joined the network, which at the time of writing operates on 5 continents58.

It is also noteworthy that some of these apps also allow "ridesplitting". For instance, with Splyt, user of the "Green Cabs" in Brussels59 can share the drive with other customers, and save up to 40% on their bill. The service can be activated both before and during the ride. Passengers are informed of other travellers in the neighbourhood, can link the use of the app to Facebook and can enter criteria that other travellers have to comply with. For instance, women can indicate that they only wish to share their ride with other women60.

5.5. Impacts

The controversies raised by on-demand ride services have been widely publicized in the popular and professional media.

On the one hand, some claim that "(t)he closest the shared-use mobility market comes to capturing the excess capacity of already owned and underused assets is in the on-demand ride sourcing market."(ITS America 2015). In other words, -on-demand ride services are claimed to have improved the overall efficiency of the transport system.

On the other hand, TNCs have been accused of unfair competition and of exacerbating traffic problems.

Regarding the first issue, it has been claimed that these services compete almost directly with traditional taxi services, but without being subject to same regulatory framework (for instance, regarding safety, screening of the drivers, vehicle maintenance, etc)61. Other points of criticism include the opacity of the pricing practices, the focus on young and affluent market segments, and negative impacts on safety and congestion (Rayle et al. 2016). Moreover, in cities where TNCs have important market shares, congestion supposedly has worsened, partly due to induced traffic, but also due to practices such as double parking in bike lanes and bus stops62 when passengers are taken on board or dropped off63.

However, as pointed out by Shaheen et al. (2015a), due the novelty of these services, independent scientific assessments of their impacts remain rare.

Anyway, most of the problems associated with TNCs can be dealt with through dedicated regulation which does not touch on the fundamental innovative aspects of the business model.

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58 https://www.iru.org/resources/newsroom/three-major-north-american-apps-partner-uptop

59 There are expansion plans in other Belgian cities.

60https://www.digimedia.be/News/fr/19359/les-taxis-verts-bruxellois-repondent-a-uber-avec-l-application-splyt.html

61http://www.economist.com/news/leaders/21601257-too-many-obstacles-are-being-placed-path-people-renting-things-each-other-remove

62 Arguably, if shared mobility leads to a reduction in parking needs, then this specific problem should largely disappear with time: it would become 'simply' a question of re-allocating the free parking space as drop-on/drop-off zones.

63 http://www.sierraclub.org/sierra/2016-2-march-april/green-life/sharing-economy-truly-green

For instance, the Municipal Government of Sao Paulo has recently proposed a decree that, if implemented, would mitigate the possible negative congestion impacts of TNCs with market based instruments. The proposed scheme can be summarized as follows: TNC would be required to make an estimate of the vehicle-kilometers driven by their fleet in the two coming months, and would have to pay a fee to obtain periodic credits. These credits could then be traded; TNCs who exceed their credits would have to pay a surcharge. This system is equivalent to a system of distance based road charging[64]. It would thus allow the city to capture the rents that TNCs gain from using public roads. Note that this system is far from perfect. There is for instance no specific reason (except political feasibility) why other road users should not be subject to the same scheme, as they also benefit from their use of publicly funded infrastructure.

5.5.1 Relevant market segment

A first important question is the identification of the actual market in which on-demand services operate. Which are the modes they are actually competing with? And could they possibly act as complements to other traditional transport modes?

Rayle et al. (2016) have conducted an exploratory study of the use of "ridesourcing" services in San Francisco. This study is based on 380 surveys collected from three ridesourcing "hotspots" in spring 2014. A key limitation of the study, which is acknowledged by the authors, is that the sample is small and may not be representative[65]. All points discussed below should be seen in that perspective.

Some key findings of the study are:

- The respondents tended to be younger and better educated than the general population, and were younger than frequent taxi users. However, the authors acknowledge that ridesourcing may become more popular among a more diverse population as it expands.
- Ride sourcing services and taxis do indeed serve a similar market demand but approximately half of the surveyed ridesourcing trips "replaced modes other than taxi, including public transit, walking and biking, and driving". However, non-car owners "were most likely to have shifted from transit."
- Respondents confirmed that "ride sourcing wait times were not only much shorter overall, but they were also markedly more consistent across day, time, and location". This appears to be especially true in outerparts of the city, which suggests that, ride sourcing is filling a supply gap in these neighbourhoods. However, the authors acknowledge that it is not clear whether these "wait-time advantage arises from technological efficiencies (i.e. , smartphone-enabled matching rather than telephone dispatch) or a greater vehicle supply (i.e , ridesourcing is not subject to regulations that restrict supply)." Note that, wherever ridesourcing is filling gaps, it may lead to induced travel.
- In relation to public transit, ride sourcing was found to act both as complement and substitutes. Compared to mass transit, ride sourcing offers smaller door-to-door travel times. There is thus a risk that "ridesourcing could "skim the cream" from public transit ridership and erode transit's ridership base". On the other hand, "ridesourcing

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[64] http://blogs.worldbank.org/transport/sao-paulo-s-innovative-proposal-regulate-shared-mobility-pricing-vehicle-use

[65] For instance, it oversampled night-time and social trips, which are more likely to be made by taxi anyway. In more general terms, San Francisco may be an a-typical market.

sometimes serves a niche demand that mass transit inherently does not serve well, like connections to transit, trips to or from low-density areas, or late-nighttrips when waiting for transit might feel unsafe." Ridesourcing may also serve habitual transit users in specific circumstances (for instance, when transit is overcrowded or when users have to carry heavy items). Seen from this perspective, ridesourcing could play a role as "a gap-filling mode that allows a generally car-free life-style".

- Although ridesourcing does not appear to have an important effect on car ownership to date, this may mainly be due to the novelty of the services. It does serve as a substitute for private car travel in specific situations (for instance, to avoid drinking and driving).

- Although the authors find that, compared "with taxi users, surveyed ride sourcing customers appear to own fewer vehicles and travel with more companions", they admit that this result may be the result of sampling bias, as the public "at the survey locations might be younger and more social than average and hence might be less likely to own a car and more likely to travel in groups".

- Concerning the global impact on traffic volumes, the authors point to a lack of "data on the extent to which drivers cruise for passengers". On the hand, because ridesourcing drivers do not rely on street hails, they "may tend to circulate less than taxi drivers". On the other hand, high demand may attract "ridesourcing drivers from more distant suburbs, whereas this effect for taxis is limited by regulation"[66]. The net effect is not known.

- In general, the authors conclude that "ridesourcing expands mobility options for city dwellers, particularly in large, dense cities like San Francisco where parking is constrained and public transit is insufficient. Thus, outright bans on ridesourcing would negate these mobility gains." However, they also acknowledge that "(r)idesourcing may also have negative aspects not addressed in this study—such as increased congestion, labor abuses, and access for the disabled—that might call for regulation."

Another recent report, by Kelley Blue Book[67], concluded that "the trend towards car and ride sharing services like ZipCar and Uber pose no real threat to new car ownership (…) 80 percent of the respondents indicated that owning or leasing a vehicle provides a sense of freedom and independence.(…) Among those survey participants who don't own vehicles, 57 percent said they didn't because of affordability issues, while only 5 percent indicated that their transportation needs were met by car- or ride-sharing.". A majority of respondent acknowledged that ridesharing could complement private driving, for instance to combat drunk driving. Thus, ridesharing would mainly act as a substitute for traditional taxi services rather than for private ownership. As the full details of the study have not been made publicly available, we cannot evaluate whether the methodology used caused any biases in the responses.

Similar conclusion have been drawn in even more recent work by the Pew Research Center (2016): "The median age of adult ride-hailing users in the United States is 33, and 18- to 29-year-olds are seven times as likely to use these services as are those age 65 and older (28% vs. 4%). Ride-hailing use is also heavily concentrated among urban residents (especially younger

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[66] Anderson 2014 confirms that there is a "large portion of interviewed drivers who drove into San Francisco from other parts of the Bay Area". However, this observation is based on a very small sample of 20 drivers.

[67] http://www.kbb.com/car-news/all-the-latest/car-and-ride-sharing-no-threat-to-new-car-sales/2100000411/#survey

urbanites and those with relatively high levels of income and educational attainment), while being consistently low among rural residents of all kinds. (…) Some 3% of American adults use ride-hailing apps on a daily or weekly basis, and around two-thirds of these regular ride-hailing users indicate that they own a car or regularly drive a personal vehicle. Although this means that a majority of these regular ride-hailing users are car owners/drivers, they are significantly less likely to own or drive a car than either occasional ride-hailing users or Americans who do not use ride-hailing at all. (…) these regular ride-hailing users rely heavily on a wide range of personal transportation options that go well beyond ridehailing alone – such as taking public transit, walking or riding a bike, or even using traditional taxi services"

A survey of US city officials by Rainwater et al. (2015) has shown that policy makers are aware of the risk that TNCs may "cherry pick" the market segments and neighborhoods they serve, whilst taxis are sometimes "required by licensing agreements with the city to service all neighborhoods and to operate 24 hours a day, seven days a week". However, the same study also pointed to "existing discriminatory patterns with cab service". Moreover, with free and flexible entry, "TNC services might spur entrepreneurship from residents living in underserved communities".

Finally, whether TNCs are competitors or complements to public transit also depends on how public transit companies and transport authorities deal with them. It is possible for these companies and agencies to set up cooperation forms with TNCs that take advantage of the strong points of TNCs (such as the high door-to-flexibility) to complement their own strong points (such as their capacity to move large quantities of people). This is actually happening. For instance, the Pinellas Suncoast Transit Authority in Florida has started a six month pilot subsidizing half an Uber ride to or from a transit station. In order not to exclude riders without smartphones or credit cards, the agency also works with a taxi company, up to $3. The six-month pilot, which started in February 2016, also works with United Taxi, so riders who don't have a smartphone or credit card can access the discount as well. Some cities with a dense urban centre but sprawled peripheries (such as Dallas) include TNCs in their official mobile ticketing app68.

5.5.2 Efficiency

Anderson (2014) argued that the overall (ecological) efficiency of ridesourcing would depend on the net effect of two opposing forces:

- On the one hand, the supply of drivers is more flexible than in the traditional taxi market and "flexible drivers can simply go offline when business is slow" (instead of cruising the streets), which should lead to a higher efficiency. Drivers can also use multiple ridesourcing apps to increase their potential market, or work as delivery drivers (see Section 8 for a more detailed discussion of this market segment).
- On the other hand, riders who come from outside the city border may "remain in their cars, in the city, waiting for the next period of demand". Moreover, it is possible that "drivers use the ridesharing income to support their own use of a private vehicle—or

even to purchase a vehicle, as some do". In this case, ridesourcing induces new private automobility.

A first attempt to compare the efficiency of ridesourcing versus traditional taxi markets has been undertaken by Cramer and Krueger (2016), who conclude that "the capacity utilization rate is 30 percent higher for UberX drivers than taxi drivers when measured by time, and 50 percent higher when measured by miles, although taxi data are not available to calculate both measures for the same set of cities."

They argue that four factors "likely contribute to the higher capacity utilization rate of UberX drivers":

- Uber's more efficient driver-passenger matching technology (mobile internet technology and smartphones compared to two-way radio dispatch system developed in the 1940s or sight-based street hailing);
- the larger scale of Uber than taxi companies in the cities that were surveyed; as a result "pure chance would likely result in an Uber driver being closer to a potential customer than a taxi driver from any particular company given the larger scale of Uber" (in other words, there are "network efficiencies from scale")[69]
- inefficient taxi regulations which "prevent taxi drivers who drop off a customer in a jurisdiction outside of the one that granted their license from picking up another customer in that location"
- Uber's flexible labor supply model and surge pricing which closely matches supply with demand throughout the day.

However, the authors acknowledge that, due to data limitations, they had to limit their study to a few major cities in the US (Boston, Los Angeles, New York, San Francisco and Seattle). Moreover, in the specific case of New York City, the "capacity utilization rates of taxi and UberX drivers are much more similar". A possible explanation advanced by the authors is that "the high population density of New York City supports more efficient matching of taxis and passengers through street hailing than is the case in other cities. "

The efficiency of traditional taxi services could be improved through the offer of shared rides ("taxi sharing"). Here as well, the existence of mobile apps has hugely expanded the potential for matching participants. Santi et al. (2014) point out that, although taxi sharing could reduce some of the negative impacts of taxis, "this comes at the expense of passenger discomfort quantifiable in terms of a longer travel time". In their work, they develop new approaches to "efficiently compute optimal sharing strategies on massive datasets", and apply these to taxi trips in New York City. They show that total trip length could be reduced by 40% or more, at the cost of only a low passenger discomfort[70], and leading to decreases in service costs,

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[69] This point has also been made in other publications: "As the firm expands the number of drivers it has in a market, the time it takes for a car to get to a customer shortens, which attracts more passengers, which in turn begets more drivers. As its business grows, drivers also have less downtime, meaning the firm can lower prices, which again attracts more users." - http://www.economist.com/news/briefing/21635077-online-businesses-can-grow-very-large-very-fastit-what-makes-them-exciting-does-it-also-make In other words, TNC are subject to a phenomenon that is quite close to the well-known Möhring effect in public transport https://en.wikipedia.org/wiki/Mohring_effect .

[70] Maximum delays of five minutes due to the sharing of the trip.

emissions and fares per capita per trip. The reduction in the financial cost of using a taxi could lead to induced demand, which is not modelled.

A large scale study on the net greenhouse gas impacts[71] of TNCs is currently undertaken by the University of California, Berkeley. The researchers will have access to data, not just from Uber and Lyft, but also from the riders. The following questions are addressed in the study: "how long the trips are (as well as the time driving to pick up a passenger); whether the rider would otherwise have driven alone, taken public transportation or not have taken the trip at all; and the fuel efficiency of the vehicles involved".[72] Results are expected in fall 2016.

5.5.3 Insurance

One of the key difficulties in the design and regulation of insurance for TNCs is that TNC drivers also use their cars for private purposes. Regulators could require that insurance policies provide different types of coverage depending on the situation. For instance, in the US, Dallas has created an approach that distinguishes three phases for insurance purposes (Rainwater et al. 2015):

- When a TNC driver is driving but is unavailable for ride services (i.e., the app is off), he must be covered by his private personal insurance.
- When a driver turns on the app, but has not yet accepted a ride, the TNC is required to provide contingent insurance to cover claims that are not covered by a driver's personal insurance.
- As soon as a driver *accepts* a ride, 'the driver or company must have primary insurance in the event of an accident'.

A lot of variants on this scheme are of course possible. There is thus no prior reason why TNCs should be subject to less stringent insurance requirements than traditional taxi services.

5.5.4 Data sharing

One of the contentious issues on the relation between on-demand ride services and public authorities is the exchange of data.

The platforms that "match" services and clients have huge amounts of data available, for instance on the following topics: accidents, driving patterns, real-time trip data, driver availability… If these data would be shared with city authorities, they could lead to improvements in the transportation network, to the development of apps showing all available transportation options, and the identification of areas that are poorly served by transport services in general (Rainwater et al. 2015).

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[71] Thus, the effects on congestion and conventional air pollutants are not being considered.

[72]   http://www.theguardian.com/environment/2016/jan/21/uber-lyft-helping-hurting-environment-climate-change?CMP=share_btn_tw

Some claim that, if TNCs can freely use the road infrastructure constructed and maintained with public money[73], it is only fair to request that the TNCs make their data publicly available as a form of counter service.

For instance, Sao Paulo has proposed a municipal decree which would require "TNCs to provide Sao Paulo with data on trip origins and destinations, times, distances and route of travel, price and service evaluation." These data could be used by the municipality to optimize the management of the road network and to vary the fees for TNCs (see the discussion in Section ***)[74].

It is also possible to conceive of partnerships between cities and TNCs that would share their data. For instance, in exchange for anonymized TNC data, the transport authority could include the TNC in its official route planning apps[75].

5.5.5 Synergies with electric mobility

We have already referred before to the possible complementarities between electric mobility and carsharing systems. If rides with on-demand ride services mainly consist in trips over relatively short distances, then this complementarity may also exist in this market segment. Major auto manufacturer GM certainly seems to think so: it has not only launched a new EV model (the Chevrolet Bolt) which significantly higher ranges, but has also acquired the intellectual property of the defunct TNC Sidecar[76].

5.5.6 People with physical disabilities

The mobility of people who are physically impaired, due to age or to other reasons is a policy issue that is likely to grow in importance in the future. Traditional policy responses include (a) making public transport infrastructure more accessible (b) the provision of Demand Responsive Transport. (DRT). We shall come back to these issues in Section 7.1.

As DRT services are often provided by taxis, this raises naturally the question whether TNCs could also be involved in this market segments. In the United States, for instance, some cities are working on regulations that would ensure that TNCs also provide services to people with physical impairments. While some cities have considered mandating a minimum percentage of wheelchair accessible vehicles in the fleet of each TNC, this has not yet been implemented in practice, mainly due to the practical difficulties this would entail. An alternative approach, which has been chosen by Dallas, is to "include a general clause in the transportation ordinance that explicitly stated TNCs could not deny service to those requiring special assistance. If a particular TNC does not have wheelchair accessible vehicles readily available, they have the option to refer passengers to another company that can provide wheelchair accessible cars" (Rainwater et al. 2015). Another approach has been chosen by Washington DC, which requires "TNCs to pay into an accessibility fund (…) which will be used for the purchase, operation, training and use of wheelchair accessible for-hire vehicles within the District. Furthermore, the legislation requires each taxi company and TNC to submit records of the requests for wheelchair

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[73] Of course, in the absence of road pricing, the same argument applies to all road users.

[74] http://blogs.worldbank.org/transport/sao-paulo-s-innovative-proposal-regulate-shared-mobility-pricing-vehicle-use

[75] http://www.fastcompany.com/3057050/fast-feed/lyft-may-share-ride-data-with-los-angeles-metro-authority

[76] http://www.automotiveworld.com/analysis/made-sharing-electric-ride-share-ready-bolt/

accessible services, as well as data on the amount of time between the reservation and service delivery" (Rainwater et al. 2015).

At the other end of the spectrum, some have suggested that public transport companies should outsource all DRT activities to TNCs, because TNCs would be better equipped to use the latest technologies than PT operators. However, this idea is controversial. For instance, it can be doubted that the typical targets of DRTs (elderly and disabled people) would be willing to adopt the smartphone-centered approach of the TNCs[77].

The very recent Communication from the Commission on the collaborative economy (COM(2016) 356 final) remains completely silent on this topic.

The Commission's proposal for a "European Accessibility Act" (COM(2015) 615 final) does not go beyond a general requirement that "Air, bus, rail and waterborne passenger transport services, the websites, the mobile device-based services, smart ticketing and real-time information and Self-service terminals, ticketing machines and check-in machines used for provision of passenger transport services shall comply with the corresponding requirements set out in Section V of Annex I." There are thus no specific provisions for TNCs.

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[77] http://www.brookings.edu/research/papers/2016/03/08-lyft-uber-transit-agency-budgets-kane-tomer-puentes

6. Ridesharing

6.1. Definitions

Shaheen et al. (2015a) define this type of services as the facilitation of "shared rides between drivers and passengers with similar origin-destination pairings." Depending on the number of people boarding a single vehicle, this can be described as vanpooling or carpooling. An essential element in ridesharing is its non-profit nature, which excludes cab sharing, taxis, and jitneys (Chan and Shaheen 2013). As carpools are difficult to record and count, they tend to be poorly documented. There are few quantitative data available on this transport mode, which is sometimes referred to as the "invisible mode" (Chan and Shaheen 2013).

Depending on the way the ridesharing is organized, Shaheen et al. (2015a) distinguish three types of ridesharing:

- **Acquaintance-based ridesharing:** the participants in the carpool are already acquaintances (for instance family or colleagues).
- **Organization-based carpools:** participants join the service either through membership or through web based services.
- **Ad hoc ridesharing**: this involves specific forms of ridesharing, such as "slugging" (which has already been discussed extensively in Section 5.4 of Deliverable 2.1) [78] [79].

6.2. Benefits

For the participants, the financial benefits can be substantial – up to two-thirds compared to the cost of commuting alone (Shaheen et al. 2015a).

Some important advantages of ridesharing include (Chan and Shaheen 2012; Furuhuta et al. 2013): shared travel costs, travel-time savings from high occupancy vehicle lanes, and reduced commute stress, mitigation of traffic congestions, fuel conservation, and reduced air pollution. However, other studies have found that some people actually enjoy commuting alone and found that there are health risks associated with shared commuting, including sleep disturbances, increased cortisol levels, cardiovascular effects, musculoskeletal injuries, fatigue-related accidents, and exposure to pollutants (see Robbins et al. 2015 for a more extensive discussion). Moreover, compared to the private car, ridesharing is less flexible and convenient. People's

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[78] In 2015, an app was developed, Sluglines, "which crowdsources data from users actively seeking a ride or rider, helps bring users to the same waiting spot and cut down on uncertainty". http://mobilitylab.org/2016/04/27/sluglining-ride-sharing-app/

[79] As pointed out by Furuhuta et al. (2013), the advantage of this type of ridesharing is that it does not require prior commitments from the participants. A drawback is that their functioning requires a lot of participants.

need for personal space and time can also be a barrier, and some people may prefer to avoid social situations (Chan and Shaheen 2012).

Robbins et al. (2015) have conducted a pilot study to investigate perceived health and well-being of vanpool passengers and drivers in an employer-sponsored vanpool program. The results indicated that, "(a)lthough it appeared that commute time did not significantly change for vanpoolers compared with driving individually, aspects of time and the contribution that vanpooling made to time management emerged as an overarching, positive theme." In other words, vanpooling resulted in stress reduction, despite some disadvantages of the system, "such as early morning pick-up time, and concerns about getting to the van on time". The study also shows the crucial role played by employer support to the vanpool services, including practical aspects such as modifications in the vans and campus environment related to parking and pick-up/drop-off of passengers and establishing a workplace culture tolerant of van rider schedules and needs. Participants found also ways to cope with issues such as the possibility to nap on the van or the establishment of rules to prevent sick passengers from riding.

6.3. Organisation and technology

Until recently, the coordination of ridesharing was mostly informal and disorganized. The coordination of itineraries and schedules was a major inhibiting factor, especially because schedules may change at short notice. At the end of the 1990s, private Internet based matching agencies emerged, but they do not appear to have fundamentally changed the modal share of ridesharing..

Furuhuta et al. (2013) have classified the target markets for matching systems as follows:

- On-demand: a casual, one-time, and irregular trip for relatively short distances requiring almost a real-time response.
- Commute: ridesharing for commuters with regular work schedule and long-term relationships.
- Long-distance: ridesharing for a long-distance trip with advanced scheduling and less restrictive requirements of meeting time and place. These include so-called event trips, which are formed among travellers who share some specific reason for travel (for instance going to concerts or to the beach)

Critical mass is crucial for ride-matching programmes. Chan and Shaheen (2013) have identified the following strategies to create this mass:

- Regional and large employer partnerships,
- Financial incentives,
- Social networking to younger populations,
- Real-time ride-matching services that employ "smartphones" and automated ride-matching software.
- Enhanced casual carpooling approaches, which focus on "meeting places".

Since 2004, technology has indeed enabled building partnerships with public agencies and large employers-and offering incentives to try carpooling, further contributing to the building of critical mass (Greenblatt and Shaheen 2015). Specialised internet services now also connect potential car poolers ("peer-to-peer ridesharing") (Shaheen et al. 2015a). This includes several start-ups who focus on this service[80], but, as we shall see below, this is also a market segment that has attracted the attention of the TNCs.

6.4. Dynamic ridesharing

The combination of mobile application and GPS enables the implementation of **dynamic ridesharing**, which can still serve the needs of participants if their travel needs change. Thanks to these technologies, "a ride request can be matched with a driver having a similar itinerary currently in proximity to the requested pick-up location"(Furuhuta et al. 2013). Agatz et al. (2012) define "dynamic ride-sharing" as "a system where an automated system made available by a ride-share provider matches up drivers and riders on very short notice or even en-route." They identify three important areas where further work is needed to optimize dynamic ride-sharing:

- **Optimization**. In realistic applications, the size of the matching problem is enormous: "thousands of riders and drivers travel between thousands of origins and destinations during the same time periods". However, for practical purposes, these matching problems need to be solved as often as once every few minutes. They therefore suggest that "(c)entralized ride-share matching may not be practical, or computationally feasible, for many larger metropolitan areas. In such cases, effective decomposition approaches will be necessary.". Such a decomposition creates important new challenges..
- **Incentives**. Although there are financial benefits to be derived from ridesharing, "without a sufficient number of drivers and riders, the chance of finding a ride, especially one close to the desired departure time, may be very small, and thus the inconvenience may outweigh the financial benefits." As already discussed above, supporting policies can be crucial in reaching the required density for a sustainable ride-share system.
- **Choice**. For participants, providing a comprehensive list of preferences (for instance regarding timing) may be difficult and time-consuming. Moreover, these preferences may vary quickly over time (for instance, depending on the day in the week). Agatz et al. have suggested that "participants may prefer to choose from a menu of available rideshare options." However, providing such a menu of ride-share options creates new coordination issues. For instance, the same driver trip or the same rider trip may end up being chosen by multiple participants.

A potentially important barrier to dynamic ridesharing is the absence of guarantee of finding a drive back from certain destinations (Agatz et al. 2012).

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[80] http://www.bloomberg.com/news/articles/2016-02-16/can-these-new-startups-convince-americans-to-carpool

6.5. Perspectives

The further development of ridesharing faces a number of behavioural barriers, the most important of which are (Chan and Shaheen (2013); ITS America 2015):

- the flexibility and convenience of the private automobile;
- the desire for personal space and time and an aversion to social situations
- the reluctance to share rides with strangers or use one's own vehicle to pick up more than one stranger

Digital recordkeeping, links with on-line social networks and rating systems could address some security and liability concerns (ITS America 2015; Agatz et al. 2012).

Chan and Shaheen (2013) identify three areas that will affect influence future developments of ridesharing:

- Technological developments such as improved Interoperability among ridesharing databases and standards for sharing open source data among ridematching companies will help to overcome the critical mass barrier. Other innovations include: "ridematch aggregators" (websites or other interfaces that search all ridesharing databases) and multimodal integration (the seamless connection of ridesharing with other transportation modes, such as public transit and car-sharing).
- "Meeting places", such as casual carpooling sites could also lead to a higher modal share of ridesharing because they do not require prearrangements. The incorporation of transponder technology into casual carpooling systems could guarantee membership and participant payment.
- Supportive policies could promote ridesharing. Chan and Shaheen give the following examples (but without discussing their cost-effectiveness): free or reduced-price access to high-occupancy toll lanes, parking cash-out (employees can opt out of a parking space and receive compensation from their employer who leases/owns the space), and pretax commuter incentives (commuter is not taxed on ridesharing expenses).

There is a clear similarity between the matching process in the case of on-demand ride services and in the case of web-based carpool systems. It is thus not surprising that TNCs are also entering this market. For instance, Uber has launched the "UberCommute" service, which is currently operating in 29 cities, while Lyft has launched Lyft Line[81]. In March 2016, Lyft has in turn announced that it would launch a carpooling service for daily commuters in the San Francisco Bay Area, enabled by the Lyft platform, in partnership with the Metropolitan Transportation Commission (MTC)[82]..

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[81]   http://www.nytimes.com/2016/03/31/technology/car-pooling-helps-uber-go-the-extra-mile.html?smid=tw-share&_r=1

[82] https://blog.lyft.com/posts/lyft-mtc-511-carpooling

However, Chan and Shaheen (2013) are very cautious about the potential of ridesharing:

> Among the industry, there is much debate over whether to emphasize technology and social networking or financial incentives and enhanced casual carpooling (…). Moving forward, more ridesharing research is needed to better understand the role of behavioural economics, interoperability, multimodal integration, and public policy, as well ridesharing's impacts on infrastructure, congestion, and energy/emissions.

In a discussion focusing on the situation in Europe, Marsden et al. (2015) conclude:

> *"This is such a new area that peer reviewed data on impacts is not robust. There are aspects of ride sharing which will act to reduce demand (through wasted single occupancy trips) but also aspects that will increase demand (through cheaper journeys) and make shared cars more cost efficient than public transport. Given that it is such a fast moving area and has the potential to become a more significant part of the mainstream transport provision this is a major gap in knowledge. This may be of particular relevance to those of the EU-13 Member States where current car ownership levels, although growing, are still lower, and where there is a range of ride-share services advertised"*

Interestingly, we see here the emergence of another recurring them in our discussion of shared mobility: the net impacts on the transport system are ambiguous, and are highly situation specific. This suggests that, in the end, it is public policy that will determine whether the technological developments of the last decade will result in an improvement or in a further deterioration of the transport system.

7. Alternative transit services

In many jurisdictions, there exists a multitude of "semi-collective" transport services in parallel with "official" public transport, such as Demand Responsive Transit (or paratransit), jitneys (or dollar vans), and shuttles.

We will first discuss Demand Responsive Transit (DRT) – note that in the US, the term Paratransit is used to design these services (Davison et al. 2012; Ronald et al. 2015; Ryley et al. 2014). DRT corresponds to transport services that, contrary to regular public transport services, can be flexible in terms of timing and/or route choices. The origins of DRT lie in the provision of transport services to mobility impaired people, but the services offered by DRT have significantly expanded in the last decade or two.

"Jitney" services refer to broadly similar services, but which are usually associated with commercial operators who have filled niches in commuting transport. Shuttles focus specifically on transport to transport hubs or employment centers.

Although all these services are broadly similar, Shaheen uses the term 'micro-transit' to refer specifically to services that use innovative ICT technologies[83].

7.1. Demand Responsive Transit (DRT)

Although there does not appear to exist a generally accepted definition within the literature, some common elements are (Davison et al. 2012):

- DRT can be situated between regular public transport services (which are usually served by buses) and completely personalised services provided by taxis.
- DRT services can be flexible on any of the following features (or combination of these features): route, origin–destination pattern and timetable. When routes are fixed, they fall in the category of jitneys (see further). When times are fixed but routes are variable, they fall under the denominator of vanpools.

Some authors include pre-booking as an element of the definition (Wright 2013), which would then be the defining element compared to microtransit, which uses more technologically advanced booking options (see further).

There are also 'hybrid' forms of DRT, combining a fixed route core allowing pre-booked deviations (up to a predefined maximum distance) and hail and ride on the fixed route section (Mulley et al. 2012).

Potential target markets for DRT services are (Davison et al. 2012, Wang et al. 2015; Neven et al. 2015; Ryley et al. 2014):

- Market segments where demand is too low for conventional buses (e.g. rural areas, night and weekends) or where greater flexibility is needed than what can be provided by

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[83] Personal e-mail correspondence between Shaheen and the author.

conventional buses. In these cases, DRT targets the general public, with schoolchildren as important subsegment.

- The elderly and mobility impaired (including non-emergency patient transport services), and, more in general, those who can afford neither private cars nor taxis. In Europe, this would be the typical clientele of DRT in an urban context.

It should be noted that some authors exclude services who limit themselves to particular groups of users from their definition of DRT – in other words, they require that the service be available for all (Wang et al. 2015; Davison et al. 2014).

DRT is close to, but distinct from, semi-flexible bus routes, which "include a reference (nominal) route that serves fixed regular bus stops; however, when there are requests from clients with limited mobility, one or more of the vehicles serving the route may diverge from this nominal path, pick up the clients from their origin and eventually drop them to a regular bus stop or to a special destination" (Dikas and Minis 2014). Note that, in this concept, the "regular" bus must be able to take on board paratransit clients (which may include mobility impaired people).

In developed countries, DRT is usually regulated (Davison et al. 2014).

DRT, especially when uniquely focusing on mobility-impaired people, is costly, and often requires public financial support (Ryley et al. 2014; Davison et al. 2014). Another solution is to rely on volunteers to drive the vehicles (Neven et al. 2015). A case study in The Netherlands has revealed that those volunteers are often retired themselves. Performing these services gives them a purpose and also helps them maintain social contacts. Thus, volunteer-based systems are not just a way to save money, they can also improve social cohesion in rural communities (Schotman and Ludden 2014)

Examples of European practices in the field of DRT are given by the INTERREG project FLIPPER[84]. Although practices vary from place to place, the main dividing line appears to be between continental Europe and the United Kingdom (Neven et al. 2015):

"Mainland European schemes typically benefit from a commitment to funding at a national level and a robust planning framework at a regional or sub-regional level (e.g.by a small number of call centers that take bookings from passengers anywhere in the country);and have been implemented within the context of an integrated network of PT. (…) In the UK, the licensing of taxi operators is locally regulated and operated. DRT services in the UK tend to be small-scale, door-to-door, and only for a defined region or specific community of people. (…) In recent years, since the deregulation of public transport services, a greater range of local stakeholders appeared to be involved in planning DRT services, and the focus has shifted more towards rural locations in order to fill the gap caused by the withdrawal of conventional bus services (Davison et al.,2014), whilst the voluntary sector continued to address the need for more specialized travel (Brake and Nelson,2007)."

All these individual market segments can evolve over time.

For instance, if conventional bus services are subsidised (or compensated for Public Service Obligations), then cuts in central governments funding can induce local authorities to consider DRT as an alternative (Wright 2013).

In Europe, DRT was initially targeting mobility impaired people, but as a result of the European accessibility and social inclusion agenda, there has been a move to accessibility for all. DRT has also increasingly been seen as means to provide accessibility in rural areas, and to provide feeder services to conventional public transport (Mulley et al. 2012, Wright 2013). In general, the cost of provision of these services appears to be high, and, in some countries, the supply of these services has been discontinued (Wright 2013). Strict eligibility restrictions for DRT targeting audiences such as the mobility impaired can lead to higher costs of provision. In some European countries, specialised flexible service have become increasingly generalist by broadening the eligibility restrictions (Battellino and McClain 2011, Schotman and Ludden 2014). As a result, resources can be shared between services and the utilisation rates of the assets have increased, lowering costs for the operators (Ronald et al. 2015; Neven et al. 2015). Some European countries, such as The Netherlands and Switzerland, organise now "nationally supported and regionally organised general access flexible transport service schemes." (Daniels and Mulley 2012).

Where the main driver behind the development of DRT was disability discrimination legislation, the specific requirements for vehicles fulfilling these services have hampered their extension to mainstream clients (Mulley et al. 2012).

Depending on the market served, DRT services are provided by minibuses or mid-size vehicles (22 to 30 seats) but also by taxi operators (Wright 2013). Based on data from feasibility sites in Italy, Austria and Greece, Wright (2013) has developed a methodology to derive the optimal vehicle size for a given demand and average trip length. However, although "it would seem that taxis provide more cost effective DRT services in areas where demand is lowest and more dispersed, whilst minibuses (perhaps provided by social/voluntary enterprises) work better on semi-fixed route patterns in more densely populated areas", Wang et al. (2015) find that the current level of evidence on optimal vehicle sizes remains weak. In regions with high seasonal variability (such as touristic areas), taxis can replace buses during the low demand season (Mulley et al. 2012).

The market segment of the elderly has evolved drastically over the last decades. On the one hand, people over 65 years have become more active and mobile. On the other hand, increased life expectations have resulted in an increasing number of people over 85 years, while important reductions in mobility are observed when people reach the age of 80 (Battellino and McClain 2011). The extent to which travel by elderly people also includes trip chaining (for which traditional public transport is not well suited), varies from location to location[85], but the need for a door-to-door service appears to be crucial (Wang et al. 2015). The general expectation is that, due to ageing populations, the demands for DRT will continue to grow (Neven et al. 2015). This growth in the number of mobility impaired people will not only affect the demand for DRT directly, but also through changes in the number and the spatial patterns of possible destinations such as health centres (Deka and Gonzales 2014).

ActiveAge (2008) points out that, for elderly people, barriers to using public transport are not limited to the physical difficulty of boarding and alighting the vehicle, or to the difficulty of moving around within the vehicle with a wheelchair or a walking aid. Indeed, these barriers also include the stress of getting to the bus stop and of using automated vending machines.

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[85] Compare the discussion Battellino and McClain 2011 with the review in Wang et al. 2015

Other stressors are "risks of slips or falls, emergency evacuation, anxiety of waiting at bus stops and handling fares, unfamiliarity of surroundings, technologies or the services themselves, and the ongoing fear of violence or threats (portrayed by the media) that appears to be a more regular occurrence in cities."

Overall, rigorous statistical analysis of the factors affecting the demand for DRT appears to be scarce (Wang et al. 2015). In a study of Lincolnshire, a predominantly rural area in the UK, Wang et al. (2015) found that, although a user survey revealed that most users were female and of pensionable age, the most frequent trip motive was work related.

In practice, DRT confront a range of challenges, the most important of which are (Davison et al. 2012; Ronald et al. 2015, Mulley et al. 2012; Daniels and Mulley 2012: Nelson et al. 2010; Enoch et al. 2006):

- When they are overly flexible in terms of schedule and /or route (and their travel times thus become too variable), they can become unsuitable to serve as feeder service to public transport hubs in urban area.
- The pricing strategy can be a sensitive matter. When DRT provide premium services, a high price would be needed to be cost-effective, but this can enter into conflict with the objective to provide mobility services to mobility-poor market segments.
- The routing decisions for DRT are very complex to model and optimize. Some of these complexities arise from the difficulty to predict behavioural responses to late-running services or no-shows by the clients.
- DRT services basically perform taxi services at PT prices. As a result, they can be perceived as unfair competitors by traditional taxicab services.
- In several countries, a clear legislative framework is absent.
- Despite the gradual extension of the scope of the services, there is a strong perception in some countries that DRT is only for mobility impaired people. This hampers the inclusion of DRT in the standard public transport offer.
- Details in the regulatory framework for public transport can act as impediments to public support for DRT schemes. For instance, if transport modes eligible for public support are defined in terms of the vehicles that are used (for instance, 'bus' or 'trams'), then financial support for DRT can be problematic if DRT uses minibuses or taxis.
- DRT is usually not included in transport planning apps.
- When DRT is provided by public transport companies who are used to serve captive markets only, there is insufficient experience with marketing to attract new clients.

On the other hand, there are also some trends that increase the potential for DRT (Davison et al. 2012; Ryley et al. 2014, Mulley et al. 2012; Nelson et al. 2010):

- An increasing feeling that conventional PT is inflexible and unreliable, especially taking into account that individuals' requirements can vary over time.
- With increasing sprawl, conventional public transport can become unviable.
- Public authorities show an increasing interest in DRT as a means to address inclusion of some specific targets groups, but also to achieve modal shift.
- On-line bookings could make DRT more convenient for the general public, but not for the target audience of "socially motivated" DRT (such as elderly people or mobility impaired ones).
- In places where DRT was running in parallel with regular public transport services, the introduction of accessible low floor busses has put an end to this duplication of costs.

- Some niches (such as airport shuttles) have already proved to be commercially viable.
- In Europe, there is potential to use DRT in orbital journeys in suburban and peri-urban areas while 'traditional' PT is used for radial routes.
- DRT could expand into goods delivery (e.g. of library books, prescriptions and post/parcels) as an additional source of income. There may also be untapped potential for transport in the "night time economy".
- Although DRT is more expensive than public transport along the main transport axes, but is cheaper than low volumes fixed route public transport.
- The most important component of variable costs are the wage costs of the drivers (at least, in the schemes that are not volunteer-based). With automated mobility, this issue will disappear, and this will increase the potential of DRT as a feeder mode for high capacity public transport.

Although the general 'low-tech' approach that characterizes traditional DRT would seem a disadvantage compared to microtransit (see further), Wang et al. (2015) have argued that, for small scale DRT schemes, the capital cost of more sophisticated solutions would not be justified. In a survey of unsuccessful DRT schemes, Enoch et al. (2006) have also argued against the "very dangerous temptation to offer too flexible a service and to include costly technological systems, when they may not be needed."

However, others have argued that incorporating new information technologies could lead to an overall decrease in operating costs (Ryley et al. 2014).

7.2. Jitneys

According to King and Goldwyn (2014),

Jitney services emerged in the United States during the 1910s and challenged streetcars for transit riders. The jitneys' point-to-point flexibility, shorter headways, and demand responsiveness allowed them to head-run streetcars—later fixed-route publicly operated buses—and poach streetcar riders. Cities enacted local laws and regulations, namely onerous insurance requirements, to discourage jitney operations and protect streetcar companies' transit monopoly (…). Despite a 100 years of regulations and heavy subsidies for transit, jitneys have continually resurfaced within niche transit markets that are poorly served by conventional systems.

King and Goldwyn further characterise the target public for jitney services as communities with low auto-ownership rates but that are excluded from planning or ignored by transit agencies and private operators. In such markets, "local entrepreneurs established informal services, such as carpools and camionetas that provide valuable connections".

According to King and Goldwyn, there are three different views on the role of jitneys:
- As a market response to an unmet demand.
- As a threat to the "public good" aspects of transit and the protection of workers
- As a low-cost opportunity to improve transit services

Jitneys can both act as substitute or as complements to conventional public transport, and, in some cases, city authorities or transit agencies have tried to use jitneys as complement to their own services (as a feeder bus for instance, or to serve areas with poor coverage or to provide transport services to mobility impaired travellers).

7.3. Shuttles

Shaheen et al. (2015a) define shuttles as "shared vehicles that can connect passengers to public transit stations or to employment centers. They can also act as replacement services for public transit lines that are undergoing repairs or maintenance."

Shaheen et al. (2015a) distinguish the following subcategories:

- distributer/circulator service, which can connect areas in urban cores that are relatively close in proximity but too far to be within walking distance
- employer shuttles

7.4. Microtransit

Shaheen et al. (2015a) define microtransit as "a more technology-enabled type of alternative transit service (…) which can incorporate flexible routing, flexible scheduling, or both." Although Shaheen et al. consider commuters to be the primary targets for these services, they argue that the "use of advanced technology has the potential to lower operating costs for services that target special populations, such as disabled, older adults, and low-income groups."

Shaheen et al. (2015a) further distinguish between the following variants:

- **fixed route, fixed schedule**: these services are similar to public transit but "customers can make requests for new "crowdsourced" routes to be created based on demand". According to Shaheen et al. (2015a), "the impact of many microtransit services is still limited."
- **flexible route with on-demand scheduling**: as an illustration of the concept, Shaheen et al. (2015a) refer to "Boston-based Bridj, a mobile application that enables customers to request a ride in select neighborhoods (…). After the Bridj system receives pickup requests, its algorithm sets a central passenger meeting spot (…). Customers then walk to the meeting spot and share a ride with other passengers that have a similar route or destination as defined by the algorithm." In the view of Shaheen et al. (2015a), this system is closer to ridesplitting and paratransit services.

Bridj is arguably the best-known example of a company that has harnessed the power of mobile applications in the transformation of alternative transit services, up to now successfully. There

are also noteworthy failures, such as Leap, which had attempted to attract a new target audience with luxury microtransit services (including wood-trimmed interiors, black leather seats, individual USB ports and Wi-Fi.). However, it turned out that the willingness to pay for premium features was not high enough to make the business model viable, and Leap had to file for bankruptcy in July 2015[86].

Jokinen et al. (2011) have used simulations to demonstrate the viability, the cost-effectiveness, the resilience and the dependability of microtransit in an urban environment, but they acknowledge that the set-up costs of such systems can be high, and that obtaining a critical mass of customers is key. Moreover, they admit that the technology used for implementing such schemes may put off some categories of passengers.

In the Helsinki area, the Kutsuplus service was terminated at the end of 2015, mainly because the density of the served area was too low[87].

7.5. Impacts

In a study of employer-provided private shuttles between San Francisco and Silicon Valley, Dai and Weinzimmer (2014-) have found that, compared to other modes, "(s)huttles are an attractive option due to their time and cost savings". However, they also found that "shuttles exacerbate the jobs-housing imbalance by enabling individuals to live farther from work. The extent to which location of shuttle stops influences residential location choice varies from person to person, though the vast majority of shuttle riders live within a short walk from the nearest shuttle stop."

Moreover, since 20% of the people interviewed during the study "say they would use public transit were the shuttles not available, the shuttles do have an impact on public transit ridership and finances."

Thus, once again, the same key questions ("is shared mobility a complement or a substitute for public transit", "what is the impact of shared mobility on urban form") re-emerge, and, once again, we have to conclude that the answer to these questions is context-specific. It certainly depends on the policy context, and more specifically, the pricing of transport.

One interesting experiment is currently ongoing in Kansas City in the US. In February 2016, a one-year pilot project was announced as a partnership between the Kansas City Area Transit Authority (KCATA), Bridj, and Ford. In this pilot, Kansas City residents will be able to reserve

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[86]   http://www.nytimes.com/2015/10/15/technology/behind-the-failure-of-leap-transits-gentrified-buses-in-san-francisco.html?smid=li-share

[87] http://sharedusemobilitycenter.org/news/killed-kutsuplus-3-takeaways-cities-pursing-mobility-demand/

seats on Bridj vehicles (Ford vans), using the Bridj app, but driven by employees of the KCATA. One noteworthy point about this pilot is that the public agency appears to be completely open minded about how the outcome will fit in its own offer. In other words, there is no prior expectation that the service will focus on the "last mile". It is also interesting that the project has given thought to the issue of the accessibility of the system for people without smartphones or credit cards. One option that has been considered is to distribute phones with limited capability beyond the reservation of a van's service[88].

Another possibility is for public transport authorities to organise their own shuttle services, as is currently the case with the Santa Clara Valley Transportation Authority (VTA) in Silicon Valley. In January 2016,the VTA has launched the VTA FLEX pilot. It combines features associated with microtransit: 26-seat shuttle busses, summoning and paying by smartphone, dynamic routing, combination of rides in real time and optimization of pick-ups and drop-offs. New itineraries are generated each day according to changes in origin-destination pairs. Compared to "commercial" microtransit system, however, there is a "public service" component: the vehicles are wheelchair accessible and have bike racks, users can also use computers or "traditional" phones for hailing the service and prices are lower than what would be the case for commercial services[89].

Building further on a study of shared *automated* mobility (see further), the ITF (2016) has developed alternative scenarios of shared mobility where two types of vehicles operate together:

- six-seat vehicles ("Shared Taxis") that offer on-demand, door-to-door shared rides
- eight-person and 16-person mini-buses ("Taxi-Buses") that serve pop-up stops on demand and provide transfer-free rides.

In the case of Taxi-Busses, rides would need to be ordered at least 30 minutes in advance, and clients would have to walk at the most 300 meters to the stop.

Both types of services can be considered as variants of DRT.

The simulation of the traffic impacts is applied to Lisbon, and includes "high capacity" transit (rail and subway services). In this scenario, there would be no need for conventional bus lines, but (if the services would not be automated), there would be a net increase in the number of drivers. Contrary to the original study (ITF 2015), automation was not considered.

They key findings of the study are: the disappearance of congestion, a reduction of traffic emissions by one third, and 95% decrease in the need for public parking. The car fleet would

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[88] http://www.citylab.com/cityfixer/2016/02/kansas-city-bridj-microtransit/462615/

[89]   http://sharedusemobilitycenter.org/uncategorized/the-silicon-valley-agency-launching-its-own-microtransit-service/

be reduced by 97%. The vast majority of trips would require no transfers, and the cost of city trips could decrease by 50% compared to current prices.

The study has also explicitly looked into the issue of social inclusion, from three perspectives: the number of all the jobs in the city that can be reached within 30 minutes starting from each grid cell[90], the number of healthcare facilities and the number of schools. For all three metrics, the simulated system performed much better than the existing system. The authors attribute this to the fact that the proposed system allows for targeted services, based on an efficient centralised dispatching system. They acknowledge that alternative dispatching systems may lead to different results, and that centralised dispatching system can lead to issues in terms of privacy and abuse of monopoly power.

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[90] In the model, the city is divided in a homogeneous grid of 200m x 200m cells which are linked to the transport network.

8. Courier network services

Shaheen et al. (2015a) define Courier Network Services (CNS) (or "flexible goods delivery") as "for-hire delivery services for monetary compensation using an online application or platform (such as a website or smartphone app) to connect couriers using their personal vehicles, bicycles, or scooters with freight". Although freight transport falls outside the scope of this study, the emergence of CNS show that the boundaries between freight and passenger transport are becoming increasingly blurred. Moreover, the problems caused by urban freight delivery have a direct impact on the efficiency of the urban passenger transport system.

Shaheen et al. (2015a) distinguish between two models:

- **P2P Delivery Services** In this variant, "anyone who signs up can use their private vehicle or bike to conduct a delivery." This includes services such as Shipbird that connect commuters with individuals seeking couriers. Thus, "P2P delivery services make use of existing personal vehicles to get items delivered", which reduces the need for a dedicated fleet for delivery services.
- In **Paired On-Demand Passenger Ride and Courier Services**, existing for-hire ride services conduct package deliveries, either in separate trips or in mixed-purpose trips where a single trip combines the transportation of passengers and the delivery of packages. According Shaheen et al. (2015a), all major ridesourcing/TNC operators have expanded their services in this direction.

In Europe, empty runs in freight range from 15 % of truck km in Denmark to 38% in Greece (Mc Kinnon 2015). Although we are not aware of any summary figures on empty runs and load factors in urban areas, the view of the European Commission (EC 2013) is that "(i)ncreasing the generally poor load factors of existing urban freight vehicles can be a very cost effective way to reduce costs and impacts." However, increasing load factors is not a panacea, as (all other things being equal) this is "not possible without driving vehicles out of their way to visit extra stops, which means longer vehicle routes and travel times".(Arvidsson 2013). Creating synergies between private passenger transport and delivery of small loads could be one approach to improve load factors without increasing vehicle routes and travel times of freight delivery vehicles.

9. Trip planning apps

9.1. Definitions

Shared mobility expands the choice set for travellers, but also leads to an increasing number of variables to reckon with, and to even more potential decisions (ITS America 2015). We have already discussed in our Chapter 2 of Deliverable 2.1 that one of the reasons why people make less than fully rational decisions, is precisely because it is cognitively impossible to perfectly and immediately process all the information that is relevant in decision making.

As a result, the potential benefits of shared mobility can only be realized if progress is made in "the availability and use of real-time information, and the options for integrated trip planning and payment." (ITS America 2015). This holds true, both at the level of the individual user and at the level of transport demand management (the latter issue will be discussed in more detail in Section 11).

Mobile trip planning apps play a crucial role in the provision of this information. A crucial element in the development of such apps has been the provision by transit operators or authorities of schedules and route maps in an open format (ITS America 2015).

Shaheen et al.(2015a) distinguish two broad categories of planning apps:

- **Single-Mode Trip Planning** These are designed for a particular mode, and include public transit and driving route- assistance apps. As busses and trams are increasingly connected to the network, an increasing number of such apps provide real time information on delays in transit systems, congestion on the road network and incident data. This creates the opportunity to provide turn-by-turn assistance.
- **Multi-modal trip aggregators** these offer a single platform for planning trips involving different modes. Depending on the app, these can include public transit, taxi services, carsharing, ridesharing, on-demand ride services, and bicycling, walking, and personal vehicles. The information provided to the travellers includes time and cost, but in some cases also fuel consumption and calories burned. Again, this information is usually based on real-time data. Some apps allow cyclists to add additional criteria for their route choice, such as safety or the topography of the route. Other features that are included in some apps include the possibility to book and pay directly for third-party services. In some cases, the real-time information is based on user provided input on overcrowding, delays and road hazards. Some apps provide incentives to the users for providing such information ("gamification"), such as online music and gift cards.

Some apps are hybrids, combining features of social networks dedicated to people practicing the same sport (cycling, running) with the provision of route information for the practice of those sports[91].

Concerning the "multi-modal" trip aggregators, we should also keep in mind that the set of "transport modes" is also constantly evolving- for instance, Google Maps is now providing "ride sharing" its own tab as a transport option[92].

9.2. Advantages

According to Shaheen et al.(2015a), trip planning apps can play the following roles:

- Assist travellers in identifying their preferred travel route and mode based on cost, environmental impact, and time considerations
- Provide step-by-step assistance as users navigate their chosen route

Shaheen et al.(2015a) also argue that such apps can enable the use of shared mobility. They point to the recent research of Gossart and Whitney (2014), who found that initial testing of the Ridescout application "indicated that 80% of users would end up using modes other than their car, with many opting for transit usage". However, as this claim is based on intentions, rather than on actual observed behaviour, it should be interpreted cautiously.

Moreover, tracking the position of vehicles by GPS has enabled the development of an increasing number of apps providing information in real time, rather than static timetables (Hallock and Inglis 2015). Watkins et al. (2011) found that "for riders without real-time information, perceived wait time is greater than measured wait time. However, riders using real-time information do not perceive their wait time to be longer than their measured wait time." They also found that "mobile real-time information reduces not only the perceived wait time, but also the actual wait time experienced by customers. (…) Mobile real-time information has the ability to improve the experience of transit riders by making the information available to them before they reach the stop." Mobile apps could thus improve the general experience of using public transport.

Until now, the development of travel apps using real-time location based data and anticipation of travel patterns based on historic data feeds has largely been the result of top-down initiatives taken by industry. It is however also possible to conceive "collaborative travel apps", "that set out to co-create value bottom up in social systems, through generalised exchange and sharing across communities" (Dickinson et al. 2015). One notable example of such an app is Waze, which uses crowdsourcing to update its travel recommendations in real time. As a result, when

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[91] http://www.theguardian.com/lifeandstyle/2016/may/09/city-planners-cycling-data-strava-tracking-app

[92] http://www.theverge.com/2016/3/15/11239108/google-maps-ride-hailing-tab-uber

information on unexpected obstacles becomes available, Waze users can reroute to avoid congested routes[93,94].

Multimodal platforms are also getting increasingly better at combining historic personal data with real-time crowdsourced data, leading to new valuable applications. For instance, the integration of these two sources of data can be used to warn travellers in advance that there are interruptions or delays on the routes they take usually, and to provide them with suggestions for alternative routes[95]. It could even go one step further and provide the travellers with financial incentives to take alternative modes or routes than their usual ones if these are overcrowded[96].

Transit operators also increasingly allow electronic ticketing. Apps who enable ticketing have numerous advantages: "mobile ticketing apps have been shown to reduce lines at traditional ticketing locations, lower the overhead costs of maintaining ticketing machines, and reduce the need for riders to carry cash or have correct change" (Hallock and Inglis 2015).

Summarizing, the integration of crowdsourced and official data leads to a "dynamic, collaborative environment of real-time information flow between travellers". (ITS America 2015),

9.3. Challenges and emerging services

Remaining challenges abound.

One important risk is the "balkanisation" of the market, "due to varying levels of integration between public and private transportation providers, and the aggregation limitations of various applications", which act as a barrier to "a seamless, integrated trip planning and payment experience" (ITS America 2015).

Some operators have taken initiatives to integrate existing systems. For instance, Lyft and China's Didi Chuxing (formerly Didi Kuaidi) have interlinked their APIs. As a result, clients of one app can also hail cars from the other[97]. In this specific case, collaboration is possible because the two TNCs involved do not operate in the same markets, and do not compete for

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[93] http://knowledge.wharton.upenn.edu/article/how-green-is-the-sharing-economy/

[94] In some cases, Waze has engaged in partnerships with city authorities, exchanging its crowdsourced data with the city's data coming from cameras, radars and other sensors monitoring the transport network, but also any information on planned mass events and road works. See https://www.waze.com/ccp

[95] http://www.cubic.com/News/Blog/Articles/ID/1108/NextCity-Cubics-Vision-for-the-Future-of-Urban-Mobility

[96] http://www.fastcoexist.com/3058075/this-amazing-app-could-integrate-every-urban-transportation-system-and-pay-you-not-to-drive

[97] http://techcrunch.com/2016/04/11/lyft-and-didi-kuaidi-launching-cross-platform-service-this-week-in-u-s/

the same customers. In situation where operators compete for the same customers; it would be difficult to integrate systems without the intermediation of a neutral third party (which could be the organising authority).,

Another issue has already been anticipated in Chapter 2 of Deliverable 2.1: if people are less than perfectly rational, it is not just the information provided by the app that affects their actual behaviour; but also its design. For instance, it has been shown that "for every sign-up related task a user is expected to complete, the sign-up rate completion diminishes" (ITS America 2015). Therefore the design of the apps is a key factor in the eventual outcomes.

Other possible applications of such apps include lift sharing or collaborative shopping. According to Dickinson et al., such apps could "empower the community to be self-reliant" and "present potential new mechanisms to support an ageing population with increasing accessibility needs". However, such apps face important challenges, such as the identification of potential users, the creation of a critical mass, devising protocols for the establishment of norms for reciprocity, the sharing of information, demonstrating the potential benefits to helpers and building trust. This discussion also brings us right back to the topic of behavioural economics, which we have extensively discussed in Chapter 2 of Deliverable 2.1.

9.4. Mobility as a Service

The development of apps that offer an increasingly wide range of mobility services can eventually result in a move to Mobility as a Service (MaaS), this is a "mobility distribution model where all of a user's transportation needs are met using a single interface and managed by a mobility service provider"[98].

An alternative definition is provided by Kamargianni et al. (2015):

> The term "Mobility as a Service" stands for buying mobility services based on consumers' needs instead of buying the means of transport. Via "Mobility as a Service" systems consumers can buy mobility services that are provided by the same or different operators by using just one platform and a single payment. The platform provides an *intermodal journey planner* (providing combinations of different transport modes: car--sharing, car rental, underground, rail, bus, bike--sharing, taxi), a *booking system*, a *single payment method* (single payment for all transport modes), and *real time information*. MaaS users can use the Service either as Pay---As---You---Go or they can purchase mobility packages based on their or their family's needs.

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[98] https://www.linkedin.com/pulse/helsinki-setting-pace-future-mobility-catherine-kargas

In practice, the actual level of cooperation within a MaaS system can vary from one situation to the other. Kamargianni et al. (2015) distinguish the six following stages of cooperation, which they illustrate with examples from across the globe:

1. Cooperation only in terms of providing discounts for combined subscriptions
2. Ticketing integration: when one smart card can be used to access all the modes taking part in the service
3. Payment integration: when one single invoice is issued for all of the customers' mobility needs
4. ICT integration: when there is a single application or online interface that can be used to access information about the modes
5. Institutional integration: when multiple modes included in the service are owned and operated by one company
6. Integration with tailored mobility packages: when customers can pre--pay for specific amounts (in time or distance) of each service tailored towards their needs.

Amongst the examples they provide, Moovel is particularly noteworthy, because it "integrates countrywide mobility in Germany[99] via a single smartphone platform. It includes public transport, car sharing, car rental, national rail, bike sharing and taxi all provided by separate operators". Although the system's integration is deep, there are also some exceptions. For instance, the bike sharing system is not integrated in the intermodal journey planning, booking and payment system. Also, it is up to the customer to link the accounts of the car sharing and the bike sharing systems to Moovel. Finally, ticketing is not integrated.

One of the few examples providing tailored services is the Swedish start-up Ubigo, which purchases urban travel volumes from the operators, and then provides combined mobility to the households, on one single platform. Households can subscribe to prepaid packages that are tailored to their needs for each participating mode (public transport, car sharing, car rental, taxi). If households exceed their budget, they are billed for the additional trips. ICT, payment, ticketing and car access are integrated in a single app[100].

Those services were tested in Gothenburg between November 2013-and April 2014.in a pilot project with 70 households. The pilot project revealed that one of the main challenges in setting up MaaS services is to convince public transport authorities to open up for a concession/reseller agreement. In partnership with Ericsson, the project is now about to be rolled out on a larger scale in one or more other cities. Ubigo will also build on its experience to support local partners outside Sweden with the Ericsson MaaS platform[101].

In all the schemes Kamargianni et al. (2015) have documented, the public transport operator and the car sharing company are the core partners, which confirms the key complementarity between these modes as alternative to private car use. Moreover, "it stands out that in most integrated projects there is only one service provider per mode per city. In some cases this is due to the fact that there is only one service provider, but in others the cooperation is only with one selected one." For large metropolitan areas with a large number of service providers, this could be an important barrier.

However, here as well, established car manufacturers are going beyond their traditional core activities, by investing in providers of MaaS software[102].

Kamargianni et al. (2015) also provide an outline of a MaaS concept for London. From a behavioural economics point of the view, the following points are especially interesting:

> *"Building on the concept of collaborative customisation, the key to successful package creation is extracting as much information as possible from the user in order to tailor the bundles to their needs. However, consumers are only able to answer a limited amount of questions before they get irritated with the process and discontinue. This is why it is important to understand the target market before creating the questions that will assist package creation. Minimising the burden to users increases the response rate to each question. In the case of MaaS--London, this means identifying the key market segments and factors that place individuals in each of these segments. These key factors and characteristics can then be turned into areas that need to be addressed during the questionnaire at the registration phase described in section 4.1. There also needs to be a "home" section of the platform where any of provided information could be changed or expanded later."*

Helsinki has announced the intention to eliminate the need for privately owned cars by 2020 through the implementation of MaaS[103]. In this concept, residents would pay a fee for mobility that would depend on their usage profiles: [104]

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[102] http://intelligentmobilityinsight.com/news/Csm

[103] https://www.linkedin.com/pulse/helsinki-setting-pace-future-mobility-catherine-kargas

[104] https://www.linkedin.com/pulse/helsinki-setting-pace-future-mobility-catherine-kargas

Urban commuter package
for 95 €/month*:

- Free public transport in home city area
- Up to 100 km free taxi
- Up to 500 km rental car
- Domestic public transport up to 1,500 km

15 minutes package
for 135 €/ month*:

- 15 minutes from call to pick up by shared taxi
- EU wide roaming for shared taxi at 0,5 €/km
- Free public transport in home city
- Domestic public transport up to 1,500 km

Business world package
for 800 €/month*:

- 5 minutes pickup across the EU
- Free taxi in home city
- Lease car and road use
- Taxi roaming worldwide

Family package
for 1 200 €/month*:

- Lease car and road use
- Shared taxi for family members with 15 minutes pickup
- Home city public transport for all
- Domestic public transport 2,500 km

*These transport service packages are examples only.

Traffic lab   www.trafficlab.fi   4.9.2014

At a more generic level, we can say that two payment models are possible [105]:

- In a **monthly subscription model**, users pay a monthly fee. In turn, they receive of bundle of services, for instance unlimited public transport user and a given number of taxi kilometres. The service is guaranteed by a "MaaS operator", who purchases the transport services in bulk. Compared to individual users, the operator probably has more market power when dealing with the individual providers of transport services, and will thus be able to negotiate lower prices for a given level of service. From the providers' point of view, an advantage of bulk purchases is that they can demand a base price for their services that does not fluctuate with daily utilization rates. In other words, this type of MaaS shifts parts of the risks from the individual operator to the MaaS operator, who is better equipped to deal with them[106].
- In a **pay-as-you-go model**, each leg in the journey is priced by the individual transport service provider. The main role of the mobile application is then to provide the users with an interface to all services in the area. This model is better adapted for environment with a high number of irregular users (such as tourists or with a high modal share of individual cars.

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[105] https://en.wikipedia.org/wiki/Mobility_as_a_service_(transport)

[106] For instance, if thanks to its size, it has better access to credit than individual taxi service operators. Moreover, if the fluctuations in demand at the level of individuals operators are not highly correlated, the daily fluctuations will cancel out at the level of the MaaS operator.

In February 2016, the world's first MaaS provider, MaaS Finland, started operations as a private company with a focus on the international market[107]. There are several ongoing pilot projects[108]. It changed its name to MaaS Global on 3 June 2016[109].

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[107] http://maas.fi/2016/02/09/maas-finland-to-revolutionize-the-global-transportation-market/

[108] See e.g. http://www.intelligent-mobility.uk/case-study-integrated-oxfordshire-imaas-pilot/

[109] http://maas.global/maas-finland-has-officially-changed-its-name-to-maas-global/

Chapter 2: Automated mobility

Authors: Laurent FRANCKX, VITO

10. Automated mobility

10.1. Definitions, history and current status

We have already stated in the introduction to this Chapter that it is very likely that strong synergies will be possible between shared mobility and another emerging technology: automated mobility. We will further elaborate on this point here.

Greenblatt and Shaheen (2015) define Automated Vehicles (AV) as "conveyances to move passengers-or freight without human intervention". They point out that the development of AVs has already started in 1977 in Japan, and has received important impetuses from the US Defense Advanced-Research Projects Agency sponsored Grand Challenge from 2004 to 2007.

Currently, AV technologies are under development, not just by auto manufacturers, but also by Tesla Motors and technology firms such as Google. Rumours that Apple is working on a similar project have not been confirmed at the time of writing (April 2016). Volvo Cars is about to launch an experiment in China, where drivers will use AVs in real life conditions on public roads[110]. Chinese web search firm Baidu and German carmaker BMW have teamed up since 2014 to develop AVs. In March 2016, Baidu has announced the intention to distribute AVs as from 2018[111]. At the time of writing, about 30 companies were reported to be working on automated vehicles[112]. Plans are not limited to automated cars: for instance, Tesla has announced that they are working on an automated bus-like system (which, based on the limited public information that is currently available, would be closer to microtransit than to traditional bus services)[113].

There are also some examples of concrete plans for the operational deployment of AVs, albeit in a (relatively) controlled environment:

- In March 2016, nuTonomy, a spinoff from MIT, announced that it was seeking approval for on-road-testing of its driverless electric taxis in a business district of Singapore. Its intention is to deploy thousands of these vehicles in a few years. One of the key competitive advantages claimed by nuTonomy is its fleet management software, which would reduce the numbers of cars needed on the street by 60%. [114]

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[110] http://intelligentmobilityinsight.com/news/CsZ

[111] http://www.investors.com/news/technology/baidu-to-test-self-driving-cars-in-the-u-s-full-launch-in-2018/

[112] http://www.businessinsider.com/30-companies-are-now-making-self-driving-cars-2016-4?r=UK&IR=T

[113] http://www.autoworldnews.com/articles/17210/20160425/elon-musk-attempts-solve-commuter-problems-self-driving-buses-via.htm

[114] http://news.mit.edu/2016/startup-nutonomy-driverless-taxi-service-singapore-0324

- The Singaporean public transport operator SMRT and the Dutch company 2getthere have announced a joint venture that will market, install, operate and maintain automated vehicle systems. By the end of 2016, they intend to commercialise 2getthere's Group Rapid Transit Systems in Singapore. Such GRT are automated minibuses that would be deployed in closed environments (such as campuses or business parks) where they would provide first-and-last-mile connectivity. Similar, but smaller vehicles, are already under operation in Masdar City in Abu Dhabi [115]

Pilot projects such as the Gateway in London and the Pathfinder in Milton Keynes are soon to start, albeit again within a confined environment[116].

Both Uber and Lyft are also setting up partnerships to develop automated vehicles, in the case of Uber with as avowed aim to "end private car ownership"[117], [118]. Uber is currently testing self-driving cars in Pittsburgh[119], while GM and Lyft have announced that they would test a fleet of self-driving electric taxis on public roads within a year[120].

In the US, the National Highway Traffic Safety Administration (NHTSA, 2013) has defined the following levels of AV functionality:

- **No-Automation (Level 0):** The driver is in complete and sole control of the primary vehicle controls – brake, steering, throttle, and motive power – at all times.
- **Function-specific Automation (Level 1):** Automation at this level involves one or more specific control functions. Examples include electronic stability control or pre-charged brakes, where the vehicle automatically assists with braking to enable the driver to regain control of the vehicle or stop faster than possible by acting alone.
- **Combined Function Automation (Level 2):** This level involves automation of at least two primary control functions designed to work in unison to relieve the driver of control of those functions.
- **Limited Self-Driving Automation (Level 3):** Vehicles at this level of automation enable the driver to cede full control of all safety-critical functions under certain traffic or environmental conditions and in those conditions to rely heavily on the vehicle to monitor for changes in those conditions requiring transition back to driver control. The driver is expected to be available for occasional control, but with sufficiently comfortable transition time.
- **Full Self-Driving Automation (Level 4):** The vehicle is designed to perform all safety-critical driving functions and monitor roadway conditions for an entire trip. Such a

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[115] http://www.channelnewsasia.com/news/singapore/smrt-and-2getthere/2713192.html

[116] https://www.newscientist.com/article/mg23030732-600-london-to-see-fleet-of-driverless-cars-on-public-roads-this-year/?utm_source=NSNS&utm_medium=ILC&utm_campaign=webpush&cmpid=ILC%257CNSNS%257C2016-GLOBAL-webpush-DRIVERLESSLONDON and http://intelligentmobilityinsight.com/news/C0D

[117] http://fortune.com/bmw-100th-anniversary-driverless-cars/

[118] http://www.investors.com/news/technology/baidu-to-test-self-driving-cars-in-the-u-s-full-launch-in-2018/

[119] http://triblive.com/news/adminpage/10484013-74/driving-self-car

[120] http://www.wsj.com/articles/gm-lyft-to-test-self-driving-electric-taxis-1462460094?mod=djemalertNEWS

design anticipates that the driver will provide destination or navigation input, but is not expected to be available for control at any time during the trip. This includes both occupied and unoccupied vehicles.

The NHTSA (2013) refers to adaptive cruise control in combination with lane centering as an example of level 2, and the Google car as an example of level 3.

Although there are no operational examples of Level 4 vehicles, there is a lot of progress being made in the area of partial automation, which is the focus of most current work (Greenblatt and Shaheen 2015). In a very recent assessment, LaMondia et al. (2016) point out that "Mercedes and BMW 2014 models both have automated steering, braking, and acceleration capabilities" while "Google has stated that it plans to have AVs on the market by 2018 and will likely be followed by 2020 by GM, Mercedes-Benz, Audi, Volvo, Nissan and BMW". The new Mercedes E-Class has the ability to communicate, not just with other cars, but also with the infrastructure[121].

A recent study by the Society of Motor Manufacturers and Traders (SMMT) shows that, in the UK, "more than half of new cars registered in 2015 were fitted with safety-enhancing collision warning systems, with other technologies such as adaptive cruise control, autonomous emergency braking and blind spot monitoring also surging in popularity."[122] In March 2016, 20 carmakers have announced that they would add automatic emergency braking as a standard feature for the US market by 2022[123].

Current level of automation (or levels that will soon be operational) go already a long way in the direction of what consumers currently expect from automated mobility. For instance, a recent survey has found that "43.5% of survey respondents said the main reason they want driverless cars is so the car can find a parking spot and park itself.", although being able to multi-task came a close second with 39%[124].

These relatively modest expectations at the consumer level need to be put in the perspective of the cost of further automation. Greenblatt and Shaheen (2015) reckon that the technology needed to enable automation (at levels 3 and above) currently costs around US$150,000, or approximately 133,000 EUR (market exchange rate of 15 April 2016). If we compare this to the current total purchase price of a private automobile (Figure 5), this exceeds even the average purchase price of luxury brands, and is about a factor 5 larger than the average for all segments.

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[121] http://intelligentmobilityinsight.com/news/CW4

[122] http://intelligentmobilityinsight.com/news/CWh

[123] http://www.investors.com/news/technology/baidu-to-test-self-driving-cars-in-the-u-s-full-launch-in-2018/

[124] http://www.techinsider.io/why-people-want-driverless-cars-2016-4

Some examples of the outstanding technological challenges are[125]:

- A crucial point is that AVs need up-to-date information on all relevant details of their environment. Contrary to what had been expected (or hoped?), combining the low resolution information from maps such as those used in existing navigation systems with the high resolution real-time information from sensors is still not enough. For instance, sensors might face problems detecting accurately road markings covered by snow or when it rains[126]
- Existing navigation systems are still not sufficiently accurate, especially in urban canyons and tunnels.

Both issues call for high resolution, three-dimensional images of the car's environment on all possible routes. Moreover, this representation should be robust for visual changes in this environment (such as the cutting down of a tree). Currently, several competing approaches are used to deal with these issues, but all remain labour intensive (even when advanced machine learning algorithms are used) and, moreover, the information collected is quickly outdated. The key question is then to what extent sensors and crowdsourced information[127] from mobile sources can compensate for this.

Other questions that need to be addressed include: how will automated vehicles cope with informal local norms in the domain of mobility behaviour? How will they react if traffic signs have been removed since the last update of their maps?[128]

Another crucial question is whether "level 3" automation is more than a (necessary) step on the way to "level 4" automation, and should be allowed in operational situations. Some have argued that, because with "level 3" automation, "the driver is theoretically freed up to work on email or watch a video while the car drives itself", it would be "unrealistic to expect the driver to be ready to take over at a moment's notice and still have the car operate itself safely"[129]

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[125]   http://www.economist.com/news/science-and-technology/21696925-building-highly-detailed-maps-robotic-vehicles-autonomous-cars-reality

[126] Another issue is that snow may be mistaken for obstacles in the road, but solutions for this problem appear to have been successfully tested in the winter of 2016 http://qz.com/637509/driverless-cars-have-a-new-way-to-navigate-in-rain-or-snow/ .

[127] For a discussion of crowdsourcing in keeping maps up-to-date, see http://www.sensorsmag.com/news/market-news/news/vehicle-sensor-crowdsourcing-transform-digital-map-ecosystem-21634   and http://www.techinsider.io/google-expert-says-smart-cities-wont-help-driverless-cars-2016-6

[128] http://www.wsj.com/articles/why-cities-arent-ready-for-the-driverless-car-1461550001

[129] http://www.theverge.com/2016/4/27/11518826/volvo-tesla-autopilot-autonomous-self-driving-car
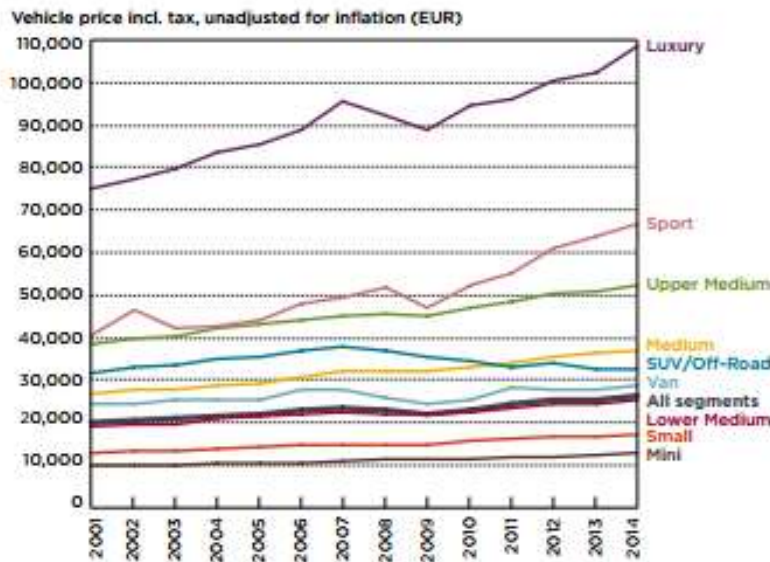
Figure 5: Passenger cars: Vehicle price (incl. tax, unadjusted for inflation) by segment (Source: ICCT 2015)

These observations points to an important issue to which we shall come back below: there is an important difference between the availability of a technology and its widespread adoption. In the case of automated mobility, the uncertainty concerning the timing of latter step is huge, and subject to a lot of controversy. We shall come back to this in the Section on the long term outlooks. First, we will have a closer look at the potential impacts of automated mobility.

10.2. Potential impacts

10.2.1 Generalities

Proponents of AV have claimed numerous potential benefits, including (Greenblatt and Shaheen 2015; Childress et al. 2015; Wadud et al. 2016; Morrow et al. 2014):

- increased safety: if AVs could eliminate all human causes of crashes, accident-rates could fall by 80 to 90 %
- better use of travel time, for instance because the travel time can be used for work or for relaxation;
- more efficient-road use and decreased congestion[130], thanks to a combination of shorter headways and a decrease in accidents
- decreases in driving-related stress

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[130] If the passenger can entirely focus on work or leisure during travel, this should also lead to a re-assessment of the opportunity cost of time while travelling. Even if congestion does not improve in terms of impacts on travel time, travelling with an AV can lead to a decrease in the *cost* of congestion.

- energy savings up-to ~80 % from platooning[131], efficient traffic flow (and thus less sporadic acceleration and braking) and parking and automated ridesharing. Additional energy savings are possible if increased safety reduces the need for safety equipment and occupant protection mass (and thus allows for lighter vehicles).
- decreases in polluting emissions, especially if AVs enable greater use of battery-electric vehicles (BEVs) or hydrogen fuel cell vehicles-(HFCVs)[132],
- provision of mobility services to people currently unable to drive
- decreased parking requirements
- the technical infrastructure required to operate and manage AVs will make it easier to track usage per kilometer, and will thus facilitate transport demand management tools such as distance-based taxes and pay-as-you-drive insurance policies
- if individual (modular) AVs could be coupled using communication systems, this could facilitate savings from weight-reduction by vehicles that are "right-sized" for the services they provide
- the high cost of AVs may accelerate the move to shared mobility – this will be discussed extensively in Section 10.4.
- roadway infrastructure could be managed dynamically. For instance, directions could be modified on individual road lanes depending on aggregate AV flows[133]. Thus, lanes that are used for the traffic driving in-town in the morning could be switched for driving out of town in the evening.
- Because AVs would give highest priority to pedestrians in terms of safety, AV reduce the need for strictly pedestrian areas, thereby increasing door-to-door mobility for mobility impaired people[134].
- In a fully automated system, travel times will become perfectly predictable (or estimates will be instantaneously adjusted in case of incidents), reducing the wait time at intermodal interchanges, and thus promoting intermodal transport[135]

Not all of these benefits require full automation. For instance, Tientrakool et al. (2011) give some estimates of potential increases in highway capacities thanks to partial automation such as the use of vehicle sensors (43%) and vehicle-to-vehicle communications (up to 273%). Other estimates are less optimistic. Shladover et al. (2013) reckon that vehicle-to-vehicle coordination of adaptive cruise control would increase capacity by 80% if the vehicle fleet was completely coordinated. On the other hand, they also show that significant improvements are possible (up to 21% increases in capacity) even with just 50% of all vehicles using the technology.

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[131] Brown et al. (2014) define "platooning" as "method of groups of vehicles travelling close together at high speed. This has the potential to reduce energy intensity resulting from aerodynamic drag." Brown et al. emphasize that the actual energy saving from platooning will be highly context-dependent..

[132] We will argue below that there are indeed important potential synergies between shared automated mobility and electric mobility.

[133] As discussed in Morrow et al. (2014), this would require a fully automated fleet and new infrastructure design.

[134] http://www.wsp-pb.com/Globaln/UK/WSPPB-Farrells-AV-whitepaper.pdf

[135] http://www.wsp-pb.com/Globaln/UK/WSPPB-Farrells-AV-whitepaper.pdf

Some of these benefits will be passed on to the car user. For instance, increased safety could (next to its immediate benefits in terms of reduction in material and physical harm) lead to decreases in the cost of insurance.

On the downside, full automation could lead to a dramatic increase in distance travelled, as the result of (Greenblatt and Shaheen 2015; Childress et al. 2015; Morrow et al. 2014):

- increased use by those currently unable to drive[136] such as young people without driving license, the physically impaired, and elderly people.
- It is not clear to what extent autonomous cars will really lead to shorter headways: one should not compare the theoretical safety distance between AVs with the *theoretical* safety distance between vehicles driven by humans as a lot of people drive closer to the preceding car than is justified on safety grounds;
- increased-numbers of trips (both occupied and unoccupied)
- a shift away-from public transit
- additional VMT/VKT due to self-parking-and self-fueling[137],
- longer trips (and especially commutes), inter alia because the opportunity cost of the time spent in traffic decreases
- increased travel to areas with limited parking facilities, followed by empty travel by the AV to a suitable parking place (or, in the case of shared vehicles, to the next customer)

Another problem is related to security: automated vehicles could be used for terrorist attacks (as car bomb for instance) without any physical risk and with much lower risks of detection for the terrorist. Moreover, automated vehicles could be hacked for malicious purposes[138]. Some argue that these security issues are not well understood (see Anderson et al. 2014).

10.2.2 Impact on energy use and emissions: generalities

In combination with other elements (such as larger, more luxurious vehicles or higher average speeds) made possible by automation, increases in distance travelled could lead to dramatic increases in energy use. Moreover, these increases in commuting distances will lead to further urban sprawl, and to buildings with a larger environmental footprint (Morrow et al. 2014). Greenblatt and Shaheen (2015) refer to work that estimates that threefold increases in energy use are possible, but consider themselves that such extreme negative outcomes are unlikely.

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[136] For these groups, being able to travel is a benefit, of course. However, the congestion and the pollution caused by their travel is a cost for society.

[137] This specific point raises another question: what will be the net impact on vehicle sales of a combination of a decrease in the number of vehicles owned at any given moment with an increase in vehicle turnover rates. Some authors have claimed that, in the long run, vehicle sales will *increase* (http://www.autoblog.com/2016/03/29/carsharing-auto-sales-increase-report/). As this report is not publicly available, we will not discuss this point further here.

[138] https://medium.com/@alexrubalcava/a-roadmap-for-a-world-without-drivers-573aede0c968#.1d198cvok

Brown et al. (2014) estimate that the net effects on energy use could range from more than 90 % fuel savings to more than 150 % increase in energy use.

Morrow et al. (2014) "group the factors that will influence future energy outcomes from widespread AV adoption into three main categories", and present them "in terms of increasing complexity of the factor being evaluated, uncertainty in the range of values, and potential influence on the resulting energy consumption." They show that, depending on the dominating factors, the net effect on primary energy consumption could range from a decrease by roughly 80% to an increase by 100%.

Table 1Key factors influencing the energy outcomes of widespread AV adoption (from Morrow et al. 2014)

Category	Key factors
Vehicles Characteristics	Weight Performance Right-Sizing
Transportation Network	Communication Roadways
Consumer Choice	Services (Passengers & Freight) Vehicle Miles Traveled Communities (the Built Environment)

An important difficulty with the assessment of net results is that the devil is often in the details.

For instance, on the one hand, Fajardo et al. (2011) point out that autonomous vehicles eliminate the uncertainty that drivers face with respect to the decision of other drivers. With automated traffic, "computerized drivers' decisions can be communicated directly to other vehicles, or to intersection-based infrastructure". Using microscopic simulation, , Fajardo et al. show that a First Come First Serve (FCFS) reservation system at intersections significantly outperforms a traditional traffic signal in reducing delay.

On the other hand, Le Vine et al. (2015) argue that "car passengers start experiencing discomfort at lower rates of acceleration than car drivers; it is therefore plausible that occupants of an autonomously-operating vehicle may wish to instruct their vehicle to maneuver in a way that provides them greater ride comfort than if the vehicle-control algorithm simply mimicked human-driving-operation." Using microsimulation, they impose acceleration/deceleration dynamics on autonomous cars that mimic those of rail systems, and show that this leads to *decreases* in the vehicle-processing capacity of a signalized intersection.

Thus, different behavioural assumptions lead to diametrically opposed conclusions with respect to the impact of autonomous vehicles on the efficiency of road intersections.

In an even more recent assessment of net impacts, Wadud et al.(2016) find "that automation might plausibly reduce road transport GHG emissions and energy use by nearly half – or nearly double them". In line with our discussion above, they find "that many potential energy-reduction benefits may be realized through partial automation", especially better connectivity between vehicles (which could enable eco-driving and platooning).

The importance of connectivity and cooperation (between vehicles, and with the infrastructure) to mitigate the possible negative impacts of automated mobility has also been discussed in the "grey" literature on the subject[139].

Maybe surprisingly, Wadud et al.(2016) conclude that "the major energy/emission downside risks appear more likely at full automation", which would be the scenario that would lead to the sharpest reduction in the drivers' opportunity cost of time. This leads Wadud et al. to conclude that "policymakers may wish to focus their energies less on accelerating Level 4 automation (which may come in due course), and more on measures that promote the application of automation toward socially desirable objectives."

Some other noteworthy points made by Wadud et al. (2016) are:

- Automation will lead to driving conditions that are more efficient than those currently simulated in the test cycles for fuel economy. This will require an update in those test cycles.
- As discussed above, automation will make the implementation of dynamic distance based road charging easier, but it also increases the need for it as a policy tool to reduce congestion.

10.2.3 Impact on long distance travel

Recent work by LaMondia et al. (2016) has addressed the specific issue of AVs' potential impacts on long-distance personal travel. They point out that "(l)ong-distance travel decisions (…) are significantly more influenced by costs and travel time than daily travel (…) due to the increased time and cost investments inherent to this travel." This is also the market segment where the impact of automation on the opportunity cost of time and on the stress linked to travel is likely to be the largest. As a consequence, this is a market segment where the introduction of AVs has an important potential effect on the frequency and the length of the trips people are willing to undertake.

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[139] https://www.linkedin.com/pulse/4-misconceptions-autonomous-cars-can-lead-cities-disaster-holguin?trk=hp-feed-article-title-like

In their work, AVs are simulated as a new travel mode "with lower perceived travel time costs (via lowered values of travel time en route) and higher travel costs (to reflect the initially high price of complete vehicle automation)." The emphasis of their work is on competition with air travel – as high speed rail is not considered as an alternative for long distance travel, the specific quantitative results of this study are of limited interest for a European context.

An interesting observation which is also highly relevant for Europe is that "new frameworks such as the Shared Autonomous Vehicle (SAV), or on-demand driverless shuttle or taxi (...) could dramatically reduce costs associated with the first- and last-mile portions of an airport trip (...) SAVs could help improve travel local travel options at the destination city and lower costs for air travelers, many of whom may previously have relied on taxis or car rentals."

Thus, in the long distance market segment, AVs can act both as substitutes and as complements for air travel (or for high speed rail). Some operators have already understood this potential. For instance, Deutsche Bahn has confirmed its intention to add automated vehicles to its system in order to offer a door-to-door transit service (Deutsche Bahn 2016).

10.2.4 The travel impact of parking versus repositioning

We have already hinted above at the source of one of the key uncertainties in the net impacts of AVs: they do not need to be parked by human drivers.

On the upside, this means that people can be driven to places without parking facilities, and will not need to cruise around to find parking[140]. The impact of not needing to find a parking place should not be underestimated. In an often quoted article, Shoup (2011) signalled that "(s)ixteen studies conducted between 1927 and 2001 found that, on average, 30 percent of the cars in congested downtown traffic were cruising for parking.[141]". Thus, if cars do not need to be parked, this could have an immediate beneficial impact on congestion. In the longer run, the reduction in parking needs could also free substantial amounts of urban space for alternative purposes – we shall come back to this point later.

On the downside, the AVs will now have to drive to places where parking is available (or cheaper), or to catch other users (which could be other family members, or, in the case of shared cars, third parties). We shall see that several studies, using different approaches, show that this "repositioning" could have an important impact on traffic flows.

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[140] Strictly speaking, you do not need an AV to perform such a service. In San Francisco, for instance, the valet-parking app Luxe allows users to request the services of attendants who park (and retrieve) cars at underused parking lots. It is not clear whether this is a viable business model – see http://www.nytimes.com/2016/03/24/technology/the-uber-model-it-turns-out-doesnt-translate.html?smid=tw-share&_r=2 for an extensive discussion.

[141] Note that this point is also sometimes misquoted. Shoup never wrote that 30% of *all* cars driving in downtown were cruising for parking: the figures refer specifically to the cars that were caught in *congested* traffic.

Levin and Boyles (2015) focus on modelling the repositioning of an empty AV by extending the mode choice in a four step model[142] to a set with three elements: AVs that park at the place of destination, AVs with empty repositioning and public transit. Only one period of time (morning peak hour) is considered. Travelers are divided according to their value-of-time (VOT) . Simulations on a city network (corresponding to downtown Austin) "show that transit ridership decreases and the number of personal vehicle trips sharply increases due to repositioning." This modal shift follows from the lower opportunity cost of time in AVs and the avoided parking fees.

However, the use of AV leads to an increase in link capacity, which offsets the additional congestion. As a result, "(a)lthough link volume increases significantly, only modest decreases in average link speed are observed." The net environmental impacts are not considered in this paper.

In this model, full automation is assumed. However, Levin and Boyles (2015) point out that, in the initial phase, AVs are likely to be expensive. This leaves a transition period for the economic sectors that would lose from full automation. This transition period has not been modelled explicitly, but Levin and Boyles discuss some of the possible behavioural responses. For instance, the model assumes that the transit mode is a bus system that shares road space with personal vehicles. The introduction of dedicated bus lanes could mitigate the impact on the bus modal share. Metro systems or bus rapid transit systems are also likely to be less vulnerable to the introduction of AVs, as they are not affected by the higher road traffic. The analysis does not address the possibility that garage owners may reduce parking prices, and leaves the modelling of different levels of automation as a topic for further research.

10.3. Long term outlook

There is considerable uncertainty regarding the future pace of adaption of automated vehicles. To give just a few examples:

- Litman (2015) expects that costs for automated vehicle will not decrease rapidly, and only expects the first benefits such "such as independent mobility for affluent non-drivers" to materialize in the 2020s or even 2030s. However, the system wide impacts we have discussed in Section 10.2 require a more widespread adoption of autonomous vehicles, and this requires important decreases in costs. Litman does not anticipate this to take place before the 2040s or even 2060s.
- Beirstedt et al. (2014) expect that capacity benefits on freeways will only occur when at least 75% of the fleet is autonomous. They do not expect this stage to be reached before 2035. Moreover, they argue that, initially, vehicle speeds and headways will be

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[142] It is interesting that one of the motivations for using a traditional 4 step-model is that these models are typically used for planning purposes with the time horizon that is currently anticipated for a large-scale penetration of AVs.

programmed conservatively and traffic efficiency will be increased by 25-35% at best by then.

- In a review of projections from industry sources and consultants, Greenblatt and Shaheen (2015) find that expected shares of AVs in vehicles sales in 2035 range from 9% to 75%. However, they also point out that even if 50% of vehicle sales in 2030 were AV , with an average vehicle lifetime of 13 to-15 years , "it would take at least 25 to 30 years for most vehicles to be-replaced."
- The most recent estimates of IHS Automotive forecast sales of nearly 21 million autonomous vehicles by 2035[143]
- One scenario (Hars 2014) assumes that by 2030, car ownership has declined to the point that just 20% of the US population own a car and that 90% of trips happen in fully autonomous mode. However, to the author's own admission, this is the end-point of a hypothetical timeline which "is an extreme of many possible futures for self-driving cars."

There is thus considerable variation in the projected evolution of the market share of AVs. Moreover, most existing projections "are based on the extrapolation of trends associated with previous vehicle technologies, expert opinions, or forecasts of supply-side variables, with very little emphasis on the underlined assumptions behind these predictions" (Kockelman and Bansal 2016). Kockelman and Bansal argue that, in order to project adaption rates, it is not sufficient to forecast the evolution of technology: one must also know the consumers' willingness to pay (WTP) for the new technologies as well as the evolution of the regulatory framework.

Another issue is user acceptance.

In an Internet-based survey covering 106 countries, Kyriakidis et al. (2015) found that "respondents, on average, found manual driving the most enjoyable mode of driving". Moreover, up to "22% of the respondents did not want to pay more than $0 for a fully automated driving system, whereas 5% indicated they would be willing to pay more than $30,000". – this should be contrasted with Greenblatt and Shaheen's estimate that full automation would currently cost around 133,000 EUR.
Other important concerns expressed in the study included software hacking/misuse, legal issues and safety.

Bazilinskyy et al. (2015) "investigated anonymous textual comments regarding fully automated driving, based on data extracted from three online surveys". They found that opinions varied a lot with 39% of the comments classified as reflecting 'positive attitude towards automated driving' and 23% as reflecting 'negative attitude towards automated driving'"

A recent (May 2016) survey in the US has found that, although only 17% of the respondents expressed concerns about the use of partially self-driving vehicles, "94.5% said they could not

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[143] http://www.detroitnews.com/story/business/autos/2016/06/07/study-autonomous-car-sales/85544688/

accept a vehicle that a human can't control manually when needed."[144] In the UK, "65% of motorists believe that a human being should always be in control of the vehicle"[145].

These results are a clear indication that user acceptance could be a major barrier in a move to full automation, and need to be included in assessments of future adaption.

In what is probably the first study to consider explicitly the three key elements determining market outcomes (supply, demand, regulatory framework), Kockelman and Bansal use the results from a survey conducted in the US, which indicate that "the average WTP (of respondents with a non-zero WTP) to add connectivity and Level 3 and Level 4 automations are $110, $5,551, and $14,589,". Note that this WTP is about an order of magnitude smaller than the estimated current cost of full automation (see Section 10.1). However,

> *"(…) perceptions, and potential behavioral responses are apt to change. For example, a large proportion (more than 50%) of individuals who do not want to pay anything for advanced automation technologies may change their perspectives, as the technology becomes proven and they see their neighbors, friends and co-workers adopt AVs to great success. Alternatively, a well-publicized catastrophe (such as a multi-vehicle, multi-fatality cyber-attack) could set adoption rates back years." (Kockelman and Bansal 2016)*

Kockelman and Bansal consider 8 different scenarios for the annual drop in technology prices, the annual increment in the WTP and changes in regulations, and conclude that "Level 4 AVs are likely to be adopted by 24.8% to 87.2% of vehicle fleet in 2045". In other words, there is more than a factor 3 difference between the upper and the lower bound of the projections - it is clear that the implications for the transport system are completely different.

However, Kockelman and Bansal also point out that future vehicle ownership patterns are likely to change, and that this still needs to be integrated in the analysis. We now turn to this issue.

10.4. Synergies with shared mobility

There are several potential sources of synergies between automated and shared mobility (Greenblatt and Shaheen 2015; Kockelman et al. 2016):

- AVs that drive themselves to the carsharing users would reduce the time needed to access a carsharing vehicle, which is an important barrier to carsharing.
- Augmented safety would decrease an operator's insurance costs, which could be passed on to the users.

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[144] http://www.govtech.com/fs/Whos-Ready-for-a-Driverless-Car-Without-a-Steering-Wheel-Many-Say-No.html

[145] http://intelligentmobilityinsight.com/news/CSV

- AVs could provide first- and last-mile connectivity to public transit and fill service gaps in the transportation-network.

In what follows, we shall refer to Shared Automated Vehicles as SAVs. We shall now discuss some recent findings on the potential impacts of SAVs, first when they constitute a small share of total mobility demand (which is arguably representative for the situation in the next 15 to 25 years), and next when they constitute (almost) the complete vehicle fleet (which would then be representative for a more distant future). The specific impacts of SAVs with alternative powertrains will be discussed in a separate section.

10.4.1 Travel demand impacts with low SAV shares

Fagnant and Kockelman (2014) highlight that an important barrier to carsharing is the need to have a nearby vehicle available. Distant SAVs could be called by members of the carsharing organisation using mobile phone applications, who would then not have to search for and walk long distances to an available vehicle. SAVs also provide carsharing organizations with a way of seamlessly repositioning vehicles in order to better match demand. How the fleet operator relocates "unused SAVs to more favourable locations in order to reduce future traveler wait times" then becomes a crucial parameter in the functioning of the transport system.

Fagnant and Kockelman use an agent-based model to test the implication of four such SAV relocation strategies, with twenty-five scenario variations to appreciate the impacts of changing the base-case scenario assumptions. The simulated road network is a gridded city, of about the size of Austin, Texas. The model takes into account the time of the day (and thus variations in congestion levels). Fagnant and Kockelman assume that only a small share (3.5%) of all trips use SAVs, and do not consider the congestion impacts of those SAVs.

The central result of the model is that each SAV can replace around eleven conventional vehicles, but ads up to 10% more travel distance than comparable non-SAV trips because the "next in-line" traveler needs to be reached. The net result is still a decrease in emissions – higher vehicle turnover rates could even lead to further improvements.

Note that the model assumes *serial sharing*: between origin and destination, no additional passengers aboard the vehicle. As we shall see below, more recent work has incorporated dynamic sharing and has shown that this substantially changes the net impacts. Moreover, Fagnant and Kockelman argue that traveller's choice set should be expanded to give flexibility in terms of the mode used, the destination, and the time of the day.

The analysis in **Fagnant et al.** (2015) is similar but is based on a more realistic network representation. This comes at a price: they now consider just one relocation strategy and model just one single day (instead of a range of seven).

Their main conclusion is that each SAV could replace around 9 conventional vehicles (which is slightly less than in Fagnant and Kockelman 2014), with an average user waiting time of one

minute. Again, they find that the repositioning of the SAVs to the next traveller or to a favourable waiting position induces additional vehicle miles (up to 8 %). However, Fagnant et al. expect that as SAV fleets grow larger, operations will become more efficient, and the costs of SAVs will drop. They also expect that parking demand could drop by more than 8 vehicle spaces per SAV, since these vehicles would mainly be in use during daytime – this raises the important policy question of the optimal use of the space that would be freed.

With respect to the environmental implications, they emphasize the reduction potential of "right sizing" the vehicles for individual trips, and the reduction in "cold' starts (which are associated with higher emissions) if vehicles travel more frequently throughout the day. Finally, they argue that the higher utilization rates of SAVs will lead to faster fleet turnover, and thus also to a quicker adoption of the most recent technologies.

Fagnant and Cockelman (2015) extend existing models to account for dynamic ride-sharing (DRS), to optimize fleet size and to forecast operators' profits. Again, they use the network of Austin for their modelling exercise, and assume that adoption levels of SAVs do not exceed 10% of all personal trip making. In a system with DRS, the direct effect of picking up and dropping off an additional passenger, and deviating from the direct route, is an increase in travel time. Nevertheless, results suggest that total travel time and travel costs decrease for SAV users. Although, in the base-case scenario, the repositioning in vehicles can lead to an increase in vehicle travel, this may be compensated if SAV membership would increase (which would allow for improved efficiency) and if users would tolerate more flexibility in trip timing and routing. Finally, they estimate that operators could realise (in the long run) a 19% annual return on investment with prices that are about a third of current taxicab fares.

Arguably the key conclusion of this section is that, as long as the share of SAVs stays under the 10%, DRS is a critical condition to avoid additional vehicle miles.

10.4.2 Impacts of (nearly) full uptake of SAVs

In the analysis of mobility systems with low shares of SAVs, it has been argued repeatedly that higher shares of SAVs could lead to an overall increase in the efficiency of the fleet. We now consider recent work that addresses the key implications of (nearly) fully automated fleets, while acknowledging that this may only become reality in several decades from now.

Burns et al. (2013) model a driverless, coordinated, specific---purpose fleet of vehicles in three different environments:

- A mid-sized US city (Ann Arbor, Michigan)
- A low-density suburban development (Babcock Ranch, Florida)
- A large and densely-populated urban context (Manhattan, New York).

They assume that customers use a smartphone app to request a ride and that the centrally dispatched autonomous vehicle picks them up and drives them directly to their destination.

After the finalisation of the trip, the SAVs drives on to the next rider – they thus require no parking space.

Burns et al "(d)etermined the number of shared, driverless vehicles needed to ensure adequate coverage and acceptable wait times during peak periods." They did not assume a complete replacement of the existing fleet, but limited themselves to the sub segment that was relevant for the network under analysis. For instance, in the case of Ann Arbor, they "focused on the 120,000 vehicles that were driven less than 70 miles per day.", as these are the trips that are assumed to take place within the network. In the case of Manhattan, only about 25 percent of residents own a car, and the study only compares SAVs with yellow taxicabs. The cost of mobility services was then estimated for a given fleet size.

In the first two case studies, such a system would lead to an important decrease in vehicle ownership (15% of the current fleet for the population driving less than 70 miles a day in the case of Ann Arbor). Moreover, the total cost of mobility would drop from 1.60 USD per mile[146] to 0.41 USD per mile (in Ann Arbor) or to 0.46 USD per mile (in Babcock Ranch). The cost could decrease even further if vehicles were "right sized" for individual trips.

In the Manhattan case, the trips performed currently by 13,000 taxis could be performed by 9,000 autonomous taxis instead.

Total mileage would increase as a result of repositioning. However, the authors argue that, if usage would increase, empty miles for repositioning purposes would decrease.

Although Burns et al. (2013) do model the use of small electric vehicles for carrying 1 to 2 occupants in urban areas, the impact on emissions is not calculated.

Zachariah et al. (2013) examine the *feasibility*[147] of using autonomous taxis in New Jersey. Their simulations are based on existing travel behaviour of the inhabitants of the state. They assume that all trips below one mile are served by walking and cycling, and that all other trips are served by autonomous taxis or by train.

Interestingly, Zachariah et al. emphasize that "(a)utonomous taxis are not meant to usurp all modes of public transportation; rather, they are most effective when used in conjunction with robust and existing highly trafficked forms of public transportation. Practicality and efficiency dictate that a multi-modal form of transportation is utilized for longer trips or for trips along which robust travel modes already exist." Therefore, the availability of train stations is included explicitly in the model.

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[146] For a car driving 10 000 miles per year, which is close to the median annual mileage for a vehicle in the US.

[147] The cost of the system is thus not addressed explicitly.

Their analysis also considers the use of casual ridesharing, and shows that this option "substantially improves transportation efficiency and eliminates congestion". This potential is especially important in denser locations (such as for instance train stations) during peak hours.

One important model limitation is that congestion is not modelled explicitly. Moreover, the SAVs travel from taxistand to taxistand, additional taxistands can be built wherever there is sufficient demand and travellers are willing to walk the "last" mile from the taxistand. The repositioning of vehicles to meet consumer demand or the impacts on parking are thus not considered.

One of the key results of the paper is "that rideshare opportunities vary spatially and temporally. (…) Certain pixels such as train stations will have a substantial potential for rideshare due to the regular mass influx of people seeking to travel. In addition, shared ride opportunities are not static throughout the day. (…) Serving high potential areas at high potential times will allow the system to reduce congestion at heavily trafficked regions during high volume time. ".

The starting point of the analysis **Spieser et al.** (2014) is the rebalancing problem faced by one-way car-sharing. The research question they address is how many vehicles would be needed to meet the transportation demand and keep the waiting times below an acceptable threshold, given that the entire private vehicle fleet is replace by SAVs. The model is applied to Singapore, based on actual transportation data.

The key results of the study are that it is possible to "meet the personal mobility need of the entire population of Singapore with a fleet whose size is approximately 1/3 of the total number of passenger vehicles currently in operation." Moreover, their results indicate that the total[148] cost of SAVs are about 50% of the total cost of human driven cars. Interestingly, in Singapore this benefit is largely due to the possibility to share the high fixed cost of car ownership[149], while in the US, it is mainly due to the increased comfort of travel, and the elimination of parking.

However, the system also leads to an increase in total distance travelled due to the realignment of vehicles. The net impact on congestion levels (which has not been modelled) and thus on travel times remains uncertain.

The **International Transport Forum (ITF, 2015)** has studied "the changes that might result from the large-scale uptake of a shared and self-driving fleet of vehicles in a mid-sized European city" (Lisbon). The study explored the following self-driving vehicle concepts:

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[148] This is the sum of the financial cost and the value of time.

[149] Which can be attributed to high ownership taxes.

- TaxiBots are self-driving cars that can be shared simultaneously by several passengers: this system thus combines automated driving with ridesharing.
- AutoVots pick-up and drop-off single passengers sequentially. This is automated driving without ridesharing.

The study assumed that the simulated urban mobility would (a) deliver the same trips as today in terms of origin, destination and timing. (b) replace *all* car and bus trips. In other words, the study considered a fully automated system without *traditional* public transport (although high-capacity public transport remains in use – see further). Technical feasibility constraints or costs were not taken into consideration.

An important difference with the approach used in Fagnant and Cockelman (2015) is that, "(w)henever a car is empty and not immediately dispatched to a new trip, it relocates itself to a station (in the TaxiBot ride-sharing system) or parks itself (in the AutoVot car-sharing system)."

The key results of the study were:

- TaxiBots combined with high-capacity public transport[150] could remove 9 out of every 10 cars in the simulated city. Even in the least favourable scenario (AutoVots without high-capacity public transport), nearly eight out of ten cars could be removed.
- However, a TaxiBot system with high-capacity public transport would result in 6% more car-kilometres travelled than today. The main driver behind this result is that these services would have to replace not only those provided by private cars and traditional taxis but also all those provided by buses. An AutoVot system without high-capacity public transport would nearly double (+89%) vehicle distance travelled as a result of repositioning and servicing trips.
- The study did not just consider the overall mobility impacts over the day, but also focused specifically on the peak hour impacts. A TaxiBot system in combination with high-capacity public transport was shown to use 65% fewer vehicles during peak hours, while an AutoVots system without public transport would remove 23% of the cars during the peak. For the TaxiBot *with* high-capacity public transport scenario, the increase in overall vehicle-kilometres travelled during peak periods is relatively low (9%). For the AutoVot car sharing *without* high capacity public transport scenario, the increase is much larger (103%), and considered to be unmanageable.

Thus, even if the system can dispense with the need for traditional public transport, the availability of a high-capacity public transport system is crucial in mitigating the negative side-effects of a fully automated road transport system, both during the peak hour and over the whole period of the day.

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[150] In the ITF study, the high-capacity public transport option was an underground system. However, the author emphasize that "other high-capacity public transport solutions such as commuter rail, Bus Rapid Transit (BRT) and Light Rail Transit (LRT) could also be used if they present a similar level of station density as Lisbon (0.65 stations/km2)."

In all the scenarios, AVs completely eliminate the need for on-street parking.- this corresponds to nearly 20% of the kerb-to-kerb street space in the model city. Moreover, up to 80% of off-street parking could be removed. The move to a fully automated personal transport system would thus free a significant amount of urban space for alternative uses.

In a mixed scenario, where only 50% of car travel is carried out by shared self-driving vehicles, the study showed that the total vehicle travel would increase by between 30% and 90%, irrespectively of the availability of high-capacity public transport. During peak hours, the overall number of cars would increase in all but one scenario, namely TaxiBots with high-capacity public transport. Thus, a gradual transition to a fully automated system would initially lead to an increase in vehicle travel and (in most cases) in the number of cars. The impact on congestion levels would depend on the extent to which the improved traffic flow of automated cards would compensate for the higher overall travel activity.

With respect to the environmental impacts, we have already mentioned that the higher usage rate of shared vehicles would lead to faster turnover of the fleet, and thus to the quicker adoption of cleaner technologies. However, as the vehicle distance travelled increases in all scenarios, the vehicle technology becomes even more important for the net environmental effects. The authors of the study have also simulated the working of fleet entirely composed of electric vehicles in order to assess the impact of re-charging times and reduced travel range. With a battery recharging time of 30 minutes and vehicle autonomy of 175 kilometres, they found that "the impact on fleet size of the deployment of a shared self-driving fleet of fully electric vehicles was minimal (+2%)".

More recently, **Levin et al. 2016** point out that existing work on SAVs is based on custom software packages, with congestion models, network structures, or travel demand that are not realistic representations of SAV behaviour. As SAVs can have a significant impact on congestion, a realistic representation of traffic flows is essential. They therefore develop an event-based framework for implementing SAV behaviour in existing traffic simulation models.

They then compare several SAV scenarios (including dynamic ride-sharing), with personal vehicle scenarios. The key result remains that, with SAVs, a smaller vehicle fleet can service travel demand in the AM peak. However, without dynamic ride-sharing, the additional empty repositioning trips increased congestion and travel times. Dynamic ridesharing improves the effectiveness of SAVs because it leads to a decrease in the demand for vehicles (and thus indirectly also to a reduction in congestion).

In summary, with an (almost) fully automated road transport system, ride sharing turns out to be a crucial condition to reduce the impact of AVs on congestion and to better spread the high cost of automation over users.. Moreover, existing studies emphasize that the full mobility benefits of SAVs will only be realised if they are complemented with high capacity public transport.

10.4.3 SAV with electric powertrains

Currently, two important barriers to a fuller uptake of battery electric vehicles (BEVS) are their limited range and their high acquisition costs when compared with conventional vehicles. We have already discussed above that shared vehicles are mostly used for relatively short trips, and are used much more intensively than vehicles that are owned by single households. Therefore, this market is a potentially important niche for BEVs. We will now discuss some recent work that studies whether additional synergies are possible if the shared vehicles are also automated.

Brown et al. (2014) give some reasons why AVs may be even better suited for electrification:

- An AV can be dispatched to meet a user's specific need, only serving trips within range
- AVs would be aware of the availability and location of charging options.
- Distributing the high upfront cost over many users can increase the relative competitiveness of PEVs as an option for many trips

Greenblatt and Saxena (2015) have estimated the greenhouse-gas (GHG) emissions and costs of autonomous taxis (ATs) with battery-electric powertrains. They estimate the combined effects of (1) future decreases in electricity GHG emissions intensity, (2) smaller vehicle sizes resulting from "right sizing" on trip basis, and (3) higher annual distance travelled, which increases the cost-effectiveness of high-efficiency (especially battery-electric) vehicles.

Their central conclusion is that "these factors could result in decreased US per-mile GHG emissions in 2030 per AT deployed of 87–94% below current conventionally driven vehicles (CDVs), and 63–82% below projected 2030 hybrid vehicles (…), *without* including other energy-saving benefits of AVs" (emphasis added). Due to these important decreases in emissions per mile, net decreases in GHG would be feasible, "even if total VMT, average speed and vehicle size increased substantially". Further savings would be possible if ridesharing would be used in conjunction with these ATs.

Kockelman et al. (2016) point out that "autonomous driving technology would remove the barrier of manual vehicle relocation and presents a driver-free method for shared EVs to reach travelers' origins and destinations as well as charging stations. In a carsharing setting, a fleet of shared autonomous electric vehicles (SAEVs) would automate the battery management and charging process, and take range anxiety out of the equation for growth of EVs". They explore the management of a fleet of SAEVs under various vehicle range and charging infrastructure scenarios in a gridded city modelled roughly after Austin, Texas.

Depending on the battery recharge time and vehicle range, one SAEV could replace from 3.7 up to 6.8 privately owned vehicles, with wait times under the 10 minutes for almost all trips. Distance travelled could increase with 7 to 14% as a result of "empty" trips while driving to

charging points or to passengers. Taking into account the full costs of such a system (including the cost of the charging infrastructure), such services could be "competitive with *current* manually-driven carsharing services" (emphasis added) for low mileage households. Compared to gasoline fueled SAVs, the competitive position of SAEV depends on the price of gasoline and (more crucially) on whether or not inductive (wireless) charging infrastructure is available[151] ,[152].

From a policy point of view, an important point highlighted by the model is "the inherent tradeoffs between reduction of induced 'empty' travel and improvement of user experience (as measured by wait times and percent of trips served)". According to Kockelman et al., this highlights "the need for a dynamic pricing scheme for SAEVs which penalizes trips that incur more relocation miles (and thereby increase subsequent trip wait times) and incentivize trips that coincide with strategic relocation (and thereby decrease subsequent trip wait times)".

Two additional complications are that, if "SAEVs become a widely adopted mode, this type of fleet can create significant demand on the electric grid and necessitate large parking areas (stations) while charging during peak hours".

As discussed in Joskow and Wolfram (2012), the effects on the grid can be mitigated through the use of dynamic pricing of electricity – interestingly, this implies that electricity pricing becomes one of the numerous pricing parameters that will affect the overall equilibrium in a system of SAEV. Concerning the second, point, taking into account the number of privately owned vehicles than can be replaced by SAEVs, the net overall demand for parking will decrease, even if the demand for charging stations increases.

Kockelman and Chen (2016) point out that, when first introduced, shared, autonomous, electric vehicles (SAEVs) will have to compete against existing modes. Therefore, they model the market potential of SAEVs by employing a multinomial logit mode choice model in an agent-based framework and different fare settings - they take into account that the owners of the SAVs can apply "surge pricing" during peak hours, to improve the fleet's performance and decrease waiting times. Pricing also takes into account unoccupied miles travelled to a charging station after completion of the trip. SAEVs are assumed to compete with private vehicles[153] and transit (city bus). Before the introduction of SAEVs, the modal split between private vehicles and transit is around 85%/15%.

The mode share of SAEVs in the simulated mid-sized city (modelled roughly after Austin, Texas) is predicted to lie between 14 and 39%, depending on the value of time and the fare.

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[151] If only traditional corded charging infrastructure is available, then "SAEVs purchased with the $7500 federal tax rebate are not price-competitive with SAVs until gasoline reaches $4.69 per gallon".

[152] Recently published research from the UK's Transport Research Laboratory (TRL) argues that wireless charging while parked should be possible around 2025 – see http://intelligentmobilityinsight.com/news/CWV .

[153] One possible extension of the model would be the introduction of privately owned autonomous vehicles.

The key assumptions of the model are that SAEVs are priced between $0.75 and $1.00 per mile under all modelled scenarios, that electric vehicles have a 80-mile-range and use remote/cordless Level II charging infrastructure. Automation costs up to $25,000 of per-vehicle[154].

The results suggest that when SAEV becomes less costly, travellers with a low VOTT will move from transit to SAEVs, and that travellers with a high VOTT may switch from private vehicles for long trips.

Kockelman and Chen (2016) also point that SAEV operators may gain by offering differentiated services: high quality services at a premium price to high-VOTT travellers and basic services at lowers prices to low VOTT travellers. Note that, although such schemes may induce higher revenues, they can also come at the cost of a lower modal share. The trade-off between revenue seeking and increasing modal share depends on the objectives of the operators. This is once again an element that may strongly be influenced by policy choices.

The model results also confirm that efficient parking pricing will reinforce the competitive position of SAEVs.

In summary, autonomous vehicles can reinforce the competitive position of BEV, but mainly indirectly: they make carsharing more attractive, and the economics of BEV are more favourable with shared vehicles than with privately owned ones. Existing work also highlights the importance of dynamic pricing, not only for the use of the SAVs, but also for electricity services.

10.5. Legal and regulatory hurdles

Several key challenges in the development of AVs will only be overcome if appropriate policies are implemented.

In the case of Europe, interoperability and compatibility between national standards and legislation are important issues, even in pilot projects. In the so-called "Declaration of Amsterdam", the EU Transport Council has defined the actions to be undertaken, respectively, by the Commission, the Member States and Industry "to work towards a coherent European framework for the deployment of interoperable connected and automated driving, which should be available, if possible, by 2019".

Another issue is the access to vehicle data by third-party service providers and competitors (ACEA 2016). ACEA has pronounced itself in favour of the "extended vehicle concept":

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[154] Which corresponds to a factor 6 decrease compared to current prices – see Section 10.2.

"An extended vehicle is understood as a physical road vehicle with external software and hardware extensions for some of its features. These extensions are developed, implemented and managed by the vehicle manufacturer. The vehicle manufacturer is fully responsible for the communication among the various parts of the extended vehicle, especially between the internal and external software and hardware components.

The extended vehicle offers open yet protected access interfaces for the provision of services by vehicle manufacturers or third parties. The interfaces need to be designed and implemented in such a way that access to the extended vehicle does not jeopardize security, safety, product integrity, data privacy or any other rights or legal obligations."

This concept is being standardized in the context of ISO[155]

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[155] http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=66975

Chapter 3: Policy implications

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11. Implications for transport modelling

In the sections above, we have seen several examples of models simulating the impacts of shared mobility and/or of AVs. All these models seem to concur on the essential qualitative impacts: a widespread use of AV will lead to important decreases in the number of vehicles (and a corresponding decrease in the need for parking space) coupled with an increase in vehicle miles travelled, unless the widespread introduction of AVs goes hand in hand with an uptake of car- and ridesharing and an important modal share of high capacity transit systems.

However, these models have been applied to a very limited number of highly stylized transport networks, and have only considered rather extreme scenarios. Transport planners need however to be able to assess what will happen in the network they manage, including in the (probably) long transition period to a (almost) completely automated and connected transport system.

There are however important gaps in current transport modelling that will need to be addressed in order to deal with the new situation. We will briefly discuss the most important emerging research needs.

11.1. Growth potential

Marsden et al. (2015) conclude that the "(e)vidence on the impact of carshare on travel dynamics is disparate and lacking robustness given the limited quality and quantity of peer reviewed literature on the topic." The lack of high quality evidence is partly due to the fact that shared mobility has only recently become an issue to reckon with.

We have shown above that growth of shared mobility has been very important in the last few years, but has until now remained limited to a niche, with often very specific socio-economic profiles and value systems. It is not clear at all to what extent the behavioural changes observed in this niche are representative for the whole population. We do not know whether the quantum leap that has been made possible with mobile apps and increasing modelling capacity has already reached the entire possible target population, or just the "early adopters", who will be followed in due time by a broader audience.

11.2. Valuation of time

We have already mentioned that the greater comfort provided by AV (and the possibility for the traveller to engage in leisure of work instead of driving) may reduce the Value of Time spent in traffic. This will affect travel behaviour through several channels:

- People will tolerate long travel times, and especially longer commutes. This can in itself lead to longer distances travelled, and, indirectly, to more urban sprawl. This sprawl

can be the result of people moving out of city centres, but the same may happen with companies.

- People will become more tolerant of "wasting" time during congestion, and this may lead to higher traffic in peak hours.

It is thus really important to better understand how the values of time will change as a result of automation (Wadud et al.2016, Childress et al. 2015).

11.3. Modelling of parking

As AVs do not need to be parked by the traveller, an important fixed cost at the end of the trip would vanish, which could induce additional demand for private travel (on top of the additional miles due to the relocation of the vehicle). These effects require a more detailed modelling of parking in the current models (Childress et al. 2015), and especially a full consideration of all the options that are now possible for the traveller (parking an AV that is privately owned, letting a privately owned AV cruise until the traveller has finished the activity that was the object of the travel, letting the privately owned AV drive back home, making the privately owned AV available for carsharing in a P2P system, renting a SAV on the way up and another SAV on the way back etc).

11.4. What is a "travel mode"?

The simultaneous emergence of new technologies and new business models leads to a virtually boundless number of possible combinations. We have seen some examples above: privately owned AVs, SAVs without ridesharing, automated vans and minibuses, privately owned AVs integrated in a P2P carsharing system, etc. Each of these combinations will be characterised by specific monetary and time costs. Traffic modellers will thus face difficult choices in determining what defines a mode in their travel models.

11.5. Impacts on road capacity

It is a common assumption in the literature that autonomous vehicles would drive more efficiently than human drivers, and this can be represented as additional roadway capacity (Childress et al. 2015). However, we have seen that some authors think that, certainly in initial phases, AVs will be programmed to drive more cautiously and conservatively than humans. Moreover, it has been argued that the positive impact on road capacity are overestimated, because humans don't respect required safety distances anyway.

11.6. Reactions from other economic actors

The studies we have surveyed until now focused on a limited number of key decision makers, assuming other decision makers will remain passive.

However, as we have pointed out in the discussion of individual papers, several stakeholders are likely to change their price settings as a response to AVs: public transport operators, managers of parking facilities, electric network operators… In the long distance segment, air and rail are also likely to modify their price policies (Wadud et al.2016).

11.7. Impact on the built environment

We have already pointed out here that AVs may encourage further urban sprawl.

Another critical impact is that the reduced need for parking space may lead to a dramatic change in the urban landscape. As there are many competing potential uses for the space that will be freed, policy will be key in determining the eventual outcome. To give just a few examples:

- Using the freed space for parks, community gardens or other forms of "green space" will have a direct impact on the attractiveness of cities, and may counteract the trend towards increased sprawl. Moreover, they will help in countering "urban heat island" effects which will become increasingly important with climate change.
- The freed space could be used to increase the size of permeable areas in cities, and thus reduce the risk of flash floods (which, again, are more likely to occur as the result of extreme weather events).
- Part of the freed space will need to be made available for recharging stations for electric vehicles.
- If it is decided to use the freed place to increase road capacity, this will lead to new induced traffic.
- In cities with a lack of affordable housing in the centre, the freed space could be used to provide for additional housing.

11.8. Ownership versus sharing

Current model results have shown that the benefits of AV are more likely to be realised (and the negative side-effects counterbalanced) if AV are fully integrated in a sharing approach (car sharing combined with ridesharing). However, there is nothing inevitable about this, and we have seen above that there are some important barriers to a fuller uptake of shared mobility. It is thus important to understand these barriers, and to make realistic assessment of the share of people (and of their socio-economic profiles) who will continue to prefer full ownership in the future.

11.9. The importance of stated preferences

Current models are estimated and calibrated against data that represent the current situation, and are thus ill-suited to model the implications of radical departures from the status quo.

In the view of Childress et al. (2015), stated preference surveys will be crucial in order to understand the effects of AVs. Childress et al. emphasize the need to understand better "the effect of ingrained habits and "lifestyle choices"". In more general terms, we would say that there is an increasing need for understanding the fundamental mobility motives of people, and that travel surveys that limit themselves to past and current behaviour will become increasingly useless.

12. Implications for transportation demand management

Throughout this chapter, we have repeatedly emphasized that changes in transport technology and innovative business model do not emerge in a policy vacuum: we need to understand what type of policies will promote specific solutions. On the other hand, these new technologies and business model also raise new policy issues, which will need to be addressed.
We will discuss some of the key issues and controversies.

12.1. Shared mobility as complement or substitute

We have seen that shared mobility, in its various forms, can be both a complement and a substitute to transit modes.

Wherever shared mobility is a complement, it is because it can be an effective tool to bridge the last and the first mile in a transport chain.

The "first/last mile" problem can have a dramatic effect on door-to-door travel time, and is therefore an important barrier to a shift from private car use to public transit. Solving (or at least seriously mitigating) the "first/last mile" problem can therefore be seen as one of the keys in reducing the negative externalities of transport.

However, "first/last mile" is also an important barrier to mobility in general for poor households who cannot afford private cars. As access to mobility in turn affects access to jobs if there is an important spatial mismatch in job accessibility, then the "last mile" problem can effectively worsen the employment prospects of poor people. (Chetty et al. 2014). This create a vicious circle: if certain neighbourhoods are struck by an important increase in unemployment (for instance, because an important share of the population in the neighbourhood works in a company that has shut down), serving this neighbourhood by public transport may become unprofitable. However, once the neighbourhood is no longer served by public transport, it can become virtually impossible for most unemployed people to find access to new jobs, effectively creating pockets of poverty. Chetty et al. (2014) have indeed found that this type of spatial mismatch in access to jobs is a source of segregation that diminishes upward mobility.

As a result, for low income households, solving the "last mile" problem can signify a step change in their prospect that should be weighted higher than the time savings of households who already have access to private mobility[156].

However, if shared mobility turns out to be mainly a substitute for public transit, the move to an increasing use of shared solutions could create a new vicious circle of decreased transit patronage and decreased service levels.

Arguably, the most important question in transport policy in the next few years will thus be whether policies can be designed that harness the strengths of shared mobility solutions to

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[156] https://www.americanprogress.org/issues/economy/report/2016/04/27/135425/can-new-transportation-technologies-improve-equity-and-access-to-opportunity/?platform=hootsuite

solve the "first/last" mile problem, and thus to promote alternative to unimodal car mobility. We have seen several examples of transit authorities or operators who are trying to do exactly this. Their experiences will need to be monitored really closely. The concept of Mobility as a Service also fits within this pattern. Even if one does not go as far as the implementation of a "complete" MaaS, partial measures (such as integrated ticketing and the provision of real-time multi-modal travel information) already goes a long way.

Public authorities can also reinforce the complementarity by providing the necessary infrastructure of bike-, ride- and carsharing in the neighbourhood of important public transport hubs (Hallock and Inglis 2015).

12.2. The regulation of on-demand ride services

We have discussed that several dimensions in the business model of on-demand ride services are controversial.
Some of these problems (such as insurance coverage and the qualification and screening of the drivers) can easily be solved through the development of specific regulations that would not touch the fundamentals of these business models.

Others, such as labour regulations, are more complex. These may require new approaches to labour legislation, such as defining hybrid categories between employees and external contractors. However, these issues are broader than the mobility sector, and are common to several sub-sectors within the "shared economy". Anyway, with the rise of automated vehicles, many of these issues will become obsolete. Moreover, we have seen that there are already new entrants in this market with new approaches to labour relations than the incumbents, and that traditional taxi markets are also adopting some of the innovations used by on-demand services.

The issue of data sharing is also important, but we have also given concrete examples of public-private cooperation that can lead to mutually beneficial exchanges between the transport authorities and the providers of on-demand services.

All in all, it does not seem unsurmountable to deal with potentially problematic aspects of on-demand services without touching the essence of their innovative approaches.

12.3. Alternative powertrains

We have seen that, under certain circumstances, a widespread use of AVs could lead to an increase in vehicle distance travelled. Although this is not a certain outcome (and is in part dependent on public policies that we discuss here), the mere risk of this happening reinforces the need for policies that promote a further greening of the vehicle fleet.

This is not the place to discuss the relative merits of different technical approaches to reducing emissions of pollutants and greenhouse gasses from vehicles. Let us just remind here that we

have shown that electric vehicles are more likely to be a competitive alternative to vehicles with internal combustion engines (ICE) in a shared fleet than when own privately. Thus, the simultaneous promotion of shared solutions and electric mobility can be mutually reinforcing.

Several elements affect this competitive position.

First, there is the issue of cost. Compared to ICE vehicles, EV have a higher acquisition cost[157] but lower operating cost. The threshold where electric vehicles become competitive to ICE vehicles is not a constant. For instance, with current low petrol prices, the breakeven point has become higher. On the other hand, public policies such as differentiated road pricing or higher fuel taxation could further increase the competitive position of EV if charges were differentiated according to emissions.

Such price instruments are not always within the remit of local authorities. However, local authorities can still use planning and zoning rules to promote the uptake of electric mobility, for instance, by dedicating part of the existing parking facilities to charging infrastructure (Hallock and Inglis 2015).

Our discussion of electric mobility has almost exclusively focused on electric *car* mobility. At the other side of the spectrum, electric bicycles could become attractive substitutes for "classical" bicycles, especially in cities where the relief and high temperatures make cycling unattractive. In places where wet weather is an important barrier to cycling, so-called bio-hybrids[158] could be an alternative.

12.4. Pricing policies

The uncertainty concerning the net impacts of shared mobility solution and of automated vehicles implies that correct pricing of transport will become more important in the future rather than less important. A correct pricing of all transport modes according to their social costs will ensure that society will be able to capture the benefits of these innovations, while avoiding the possible disadvantages (which are mostly related to the risk of increased traffic volumes if automation does not go hand in hand with increased sharing and high quality public transit)

To some extent, optimal pricing will be privatised if SAV become the dominant mode. Indeed, if the operators of SAVs are allowed to set their prices freely, one would expect that they would apply "dynamic pricing", where VMT travelled during the hours of peak demand would be priced more than VMT travelled outside the peak hour. Thus, the widespread use of SAVs would effectively result in a pricing of mobility that would come close to the economists' ideal of dynamic distance based road sharing.

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[157] Even if these are rapidly decreasing,

[158] This refers a 1+1 seater, which is similar to a bicycle with a electrically-assisted drive system but with two front and rear wheels, a luggage compartment and a roof for weather protection. It could be used on cycle tracks. - http://intelligentmobilityinsight.com/news/CWb

On the other hand, the pricing of distance travelled will need to be coordinated with the pricing of other services. For instance, parking spots will also need to be subject to "smart pricing"[159]. With electric vehicles, we have already discussed that smart pricing of electricity would also be needed.

12.5. Public transit

Finally, there is the issue of public transit.

We have argued above that policies are conceivable that could reinforce the position of public transit by solving the "last/first" mile problem through shared solutions. However, there are definitely some niches where shared solutions such as microtransit are likely to outperform traditional transit services. Moreover, the rise of AVs will reduce the opportunity cost of time spent in car travel, and this will further undermine the competitive position of some transit services.

Without going as far as the scenarios assumed by the ITF (2015), we can reasonably expect that, in the future, transit will increasingly concentrate on the task it is good at: moving huge quantities of people from one transport hub to the other. Whether this can only be implemented by metro, light rail, or BRT systems, or whether traditional bus services still have a role to play in such a landscape, remains an open question.

12.6. Accessibility

Until recently, the mobility of elderly or mobility impaired people confronted governments with two costly options. Either they could require buses and trams to be made accessible to everyone, or they could organise Demand Responsive Transport. While DRT services have the advantage that they do not require the complete rolling stock to be made accessible, they remain costly. DRT systems are also used to improve the accessibility of areas with very low population densities. When allowed, informal alternative transit systems cater to the transport needs of the urban poor who are not well served by traditional public transport.

Modern communication technology holds the promise of improving the efficiency of DRT or alternative transit systems, because they enable to group rides of people with similar origin-destination pairs. Preliminary work by the ITF (2016) confirms that such types of shared mobility hold the promise of improving accessibility to jobs, healthcare and schools. Shared mobility could thus play an important role in the fight against social exclusion.

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[159] See Millard-Ball et al. (2014) for an extensive discussion of a recent pilot project with dynamic parking pricing in San Francisco.

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