Chapter 3
Digitalization Trends

Abstract In parallel with the policy-driven decarbonization trend discussed in Chap. 2, the transport sector is currently affected by a bottom-up strong technological push by digital technologies at different maturity levels. Potential game changers include Mobility-as-a-Service, shared mobility, autonomous vehicles, and other effects of extra-sector digital technologies (e.g., online platforms, virtualization, e-commerce). This chapter will be dedicated to discussing the possible impact of these technologies in the transport sector, with a focus on the urban context, which is the first being affected by these changes.

3.1 Introduction

Digital technologies are proving to be a game changer in multiple domains, thanks to the possibility of supporting new business models and increasing the efficiency of traditional schemes. The availability of huge computational power and vast amount of data gathered from different sources helps the development of accurate algorithms and the deployment of new services for the customers. Today, a large part of the population worldwide is connected to the internet, and an increasing share of traffic is related to mobile connections. People use smartphones to connect to friends, watch movies and videos, listening to musing, shopping online, finding travel, and accommodation solutions. Smartphones are gradually becoming a key tool to access a wide range of services, and the possibilities offered by digital technologies are in continuous evolution.

Transport is no exception. Web platform is being used, just as in other sectors, to support different sharing economy solutions. Urban citizens in different parts of the world can access shared fleets of cars, bikes, and scooters through their smartphone, or they can just opt for a driver to pick them up to their desired destination. The users may be even able to compare different mobility options, to find the most cheap, fast or comfortable solution for a given trip in any given moment, based on live data on the traffic conditions. Mobility is increasingly being seen as a service, and the traditional model centered on private cars is being challenged by the possibility of paying for the actual mobility needs rather than owning a personal vehicle, with
potential advantages for cost and convenience. Furthermore, the future deployment of connected and shared automated vehicles may completely change the way people move.

Technological development is not the only aspect. There is a parallel change of mindset, especially for younger generations, which may have different habits, values and needs. The users’ behavior is a key for the success or the failure of different mobility models (Cohen, 2019), and there is a large segmentation of preferences and choices across countries, gender, age, and income. National and local policies will also have a crucial role in supporting specific technological solutions, mainly driven by the potential advantages that they could provide to citizens.

However, an additional aspect to be considered is the potential digital divide triggered by these innovative solutions, which can exacerbate the difference among low-income and high-income classes, young and old generations, urban and rural citizens. These growing dualities may be caused by differences in access to technologies related both to financial availability, but also to the digital know-how of different classes of citizens (including literacy, gender, and age).

This chapter will consider the main ongoing trends supported by digital technologies, including Mobility-as-a-Service (MaaS), shared mobility, autonomous vehicles, data-driven mobility planning, and external digital trends that have an indirect effect on mobility demand and behaviors.

3.2 Mobility-as-a-Service—A New Way of Thinking?

Mobility-as-a-Service (MaaS) is based on the possibility of exploiting digital platforms to support the users in choosing multimodal trips, to get the most from the opportunities provided by each mode to fulfill specific requirements. A key aspect is to provide to the travelers updated information on the alternative possibilities, increasing the flexibility of the available options and the resilience of the trip planning against potentials delays or the need of changing itinerary during the trip itself. To provide such information a complex integrated digital platform is required, to collect all the available data from different sources and provide the users with a clear and synthetic dashboard containing all the relevant information to support their trip planning and re-planning when necessary.

The implementation of an effective MaaS platform, which is starting to be tested in different cities worldwide, requires as backbone an efficient public transport system, on which alternative modes could be integrated, including shared mobility, taxi cabs, and active modes. MaaS can be developed at different levels, from a basic system that help the users to compare the available travel possibilities, to a totally integrated environment where the customers can buy each travel solution through a single account, or even pay flat rates to have access to an unlimited number of trips over a certain time period (e.g., monthly). While the former level is already available from multiple platforms in different cities worldwide (e.g., Google Maps, Moovit,
3.2 Mobility-as-a-Service—A New Way of Thinking?

Table 3.1 Available pricing plans for Helsinki, November 2019

| Plan             | Whim Urban 30       | Whim Weekend       | Whim Unlimited | Whim to Go         |
|------------------|---------------------|--------------------|----------------|-------------------|
| Price            | €59.7 (30 days)     | €249 (30 days)     | €499 (month)  | Pay as you go     |
| Public transport | 30-day ticket       | 30-day ticket      | Unlimited single tickets | Pay as you go     |
| City bike        | Unlimited           | Unlimited          | Unlimited      | Not included      |
| Taxi (5 km)      | €10                 | −15%               | Unlimited      | Pay as you go     |
| Rental car       | €49/day             | Weekends           | Unlimited      | Pay as you go     |

Source: MaaS Global (2019b)

Citymapper), the latter is currently being tested in some cities to gain experience and verify the effect of users’ behavior.

Probably, the most interesting case study today is Whim, an app developed by MaaS Global and initially operated in Helsinki, Finland (MaaS Global, 2019b). The app allows the users to plan their journeys over different modes (including public transport, taxis, bike, and car sharing) through their single platform, and propose different pricing schemes, from pay-as-you-go to all-inclusive plans based on a monthly fee. Whim is in operation in Helsinki from the end of 2017, and is currently in available also in Birmingham, Antwerp, and Vienna, although still with limited pricing plans. The current pricing plans available in Helsinki are reported in Table 3.1, to give an idea of the available options and their price. As a comparison, a public transport single ticket in Helsinki costs €2.80, and a 30-day ticket €59.70 (or €53 if the customer chooses an annual subscription), which is the very same price of the Whim Urban 30 pricing plan. While these plans are still at an early phase, the economic sustainability of MaaS business models will need to be demonstrated in the long run.

The company has recently completed a new funding round, including funds from BP Ventures and Mitsubishi Corporation, with the aim of expanding their market to other European cities, Singapore, Tokyo, and North America in 2020 (MaaS Global, 2019a). Whim reached a total of over 6 million trips from its launch, considering all the cities in which is operating. However, many questions related to the potential effects of MaaS still wait for an answer. The key point is if MaaS will be able to shift users from private cars to more sustainable transport modes, or if indeed if all-inclusive pricing plans will lead to a rising transport demand for less effective solutions.

A white paper on the analysis of operational data of 2018 in Helsinki gives some preliminary insights (Ramboll, 2019), although the results are based on the first year of operation, which includes a continuous increase of both registered users and available modes. Some results show that the total number of trips remains the same (an average of 3.3 daily trips), but the largest modal shift in Whim users is from active modes (walk and bicycle) to public transport. This effect may increase the quality of life of the users, by allowing them to save time of travel more comfortably, but at the same time it is increasing the transport demand for motorized modes. Car
usage seem to remain the same across the two user groups, but to clarify this aspect additional research is needed on a larger set of data, preferably across different cities.

While MaaS is currently an option for early adopters, its extension to a wider global audience will probably need to face additional issues, including the potential digital divide across generations, the interaction with local regulations in different countries, the ownership of the platforms (public vs. private), potential issues with privacy for users data (as will be discussed in more detail in Sect. 3.5). As already discussed, the potential success of MaaS will be linked to the possibility of demonstrating its capability of triggering a shift toward sustainable transport.

A crucial aspect for the future deployment of MaaS in different cities will be the choice of the business model, and in particular how the digital platform will be built, and which stakeholder will be in charge of operating it. Three basic models are available, with different actors as integrators and multiple aspects to be considered when choosing a solution over another, including alignment with policy goals, market penetration, social inclusion, innovation, customer orientation, impartiality, and data availability for public authorities (UITP, 2019). These models are summarized in Fig. 3.1. The first option is the implementation of a free market open to different MaaS operators, which can define individual agreements with transport operators. This solution may lead to a high degree of innovation and customer service, but with high perceived risks for social inclusion and impartiality, as well as limited data transparency toward public authorities to support local policies. On the other
hand, the second solution is based on the idea of exploiting the already available public transport operator to directly act as mobility aggregator, by integrating other modes. While this would obviously lead to higher guarantees in terms of social rights, impartiality, and policy support, the innovation may be significantly slowed down, as well as the potential competitiveness and attention to customers. A third model, which is somewhat a hybridization of the previous two, would be based on a common open platform defined by clear communication standards, as a backend for different MaaS providers competing on the frontend services to the users. However, while this model provides an interesting opportunity to combine the advantages of the other two, the financing required to develop and operate the open platform may be a significant issue (UITP, 2019).

A final aspect related to MaaS, which is also a result from the first operational data, is the importance of being supported by a reliable and high-quality public transport service, which should represent the backbone of urban mobility, coupled to other transport modes for first-mile and last-mile solutions.

3.3 Shared Mobility—Sharing Assets or Trips?

The concept of shared mobility embraces a large variety of technologies and mobility models, from car sharing, bike sharing, and other shared vehicles (e.g., electric scooters) to ride-hailing and carpooling, which in turn involves the sharing of the very same trip by multiple users. These models have a different diffusion in world regions, depending also on existing contexts and specific problems (such as population density, income levels, pollution, and congestion levels etc.). However, they are generally appearing in urban contexts, especially in large cities where the high density of inhabitants allows a more interesting economic profitability.

The most significant aspect that diversifies shared mobility options is whether they are based on the sharing of a vehicle at different times, or rather on the aggregation of different users that need to do the same trip. All the shared mobility options have in common the aim of going beyond the usual mobility model centered on private car ownership, either by providing the users with alternative transport modes, or by increasing the average load factor of cars, that usually remains well below two people per car in many developed countries.

3.3.1 Car Sharing

Car sharing has seen a large number of applications in the second half of the twentieth century, both in Europe and North America, with the roots of car sharing model dating back to 1948, in Zurich (Shaheen, Sperling, & Wagner, 1998). These mobility models, as alternatives to car ownership, were developed to increase the usage of cars and make them more profitable. Moreover, most companies were publicly backed,
with the aim of fostering societal benefits such as lower parking needs as well as expected lower car usage related to the different pricing mechanism. In fact, while car ownership is based on high fixed costs and relatively low operational costs (especially in the USA, where fuel costs are usually lower), the car sharing pricing mechanisms were based on an annual fixed fee and a variable fee related to the actual car usage, with the aim of discouraging an excessive use of the cars. Car sharing models were generally attractive to users with a medium annual car mileage, since occasional users were more attracted from car rental (discouraged by car sharing’s annual fee), and for users with high usage, a private car was more convenient. However, car sharing involved additional benefits, such as no ownership responsibilities and the potential access to different cars sizes based on the specific purpose of the trip (when available in the car fleet).

Car sharing models evolved throughout the decades thanks to different technological innovations, especially in matching the available car fleets with the users’ demand. This aspect was significantly improved with digital technologies in the last decade, thanks to the possibility of easily checking in realtime available cars based on the position of the user, and to go straight through the booking and paying process. This technological development, in parallel with local policies supporting lower private cars usage due to environmental concerns, has unlocked new business models, pushing different companies to offer free-floating car sharing fleets to travelers, especially in large cities.

Car sharing operators claim different advantages in comparison with privately owned cars, including the higher utilization rate, the lower emissions thanks to a faster fleet replacement, lower parking needs thanks to higher user-per-car rates. However, a key aspect is whether car sharing is able to trigger a shift from private cars or if it ends up in providing the possibility of using a car to people that were used to rely on public transport. This latter case may reflect an increased quality of life for citizens, but with higher environmental impacts. Research works have found mixed results, depending on the specific case study. A key driver appears to be the interaction with public transport: cities with car sharing services oriented to provide first- and last-mile solutions in integration with available public transport are more likely to gather environmental benefits. On the other hand, car sharing often represents an interesting alternative to public transport, providing better flexibility and comfort, although at a higher price. Local policy actions are crucial to foster an integration with public transport, by defining specific regulations for the operation of car sharing and also by implementing MaaS platforms to provide the users with a single platform for multimodal trips (see Sect. 3.2).

### 3.3.2 Ridesharing

Ridesharing companies, also known as ride-hailing services, provide mobility services that are similar to taxicabs, by matching passengers with drivers exploiting websites or mobile applications. They have similar business models of other sharing economy companies, limiting their activity to the ownership and management
of the digital platform, without owning any vehicle or other significant assets. For this reason, ridesharing companies have been able to operate without the need of respecting the taxicabs regulations in many countries, resulting in lower operation costs leading to lower prices for the final users. Moreover, they were also able to provide access to mobility to poor or isolated neighborhoods that are not regularly served by taxicabs. However, many countries and cities have implemented specific regulation to level the playing field among ride-hailing and traditional taxicabs, and in some jurisdictions, they have been even banned.

Web-based ridesharing companies appeared in the last decade in the USA, and the two most notable examples are now Uber and Lyft, which have been in a continuous competition since their creation in the early 2010s. Since both consider drivers as independent contractors rather than employees, in many cities several drivers are registered on both platforms. Uber and Lyft are both characterized by aggressive business models, which resulted in several criticisms on different aspects, mostly complaints from taxi drivers for illegal competition, and lawsuit filed by drivers that were not receiving adequate compensation. These problems have pushed several jurisdictions to develop specific regulations for ridesharing operation, mainly at the city level.

The evolution of Uber and Lyft is an example of how digital technology can support disruptive solutions in transport, although the benefits are still to be proven. Both companies are still showing significant losses (0.9 b$ for Lyft and 1.8 b$ for Uber in 2018), and a change of this trend would require either higher fares for passengers or (even) lower compensation for drivers, which are already often earning revenues lower than minimum wages after taxation. Moreover, their users are mostly shifting from public transport rather than private cars, with negative effects on urban traffic and pollution. Both companies have introduced the possibility of sharing rides, to switch toward a more sustainable use of their vehicles. However, research studies in New York and San Francisco have demonstrated that this effect remains limited, and the net effect of ridesharing services is an increase of urban traffic. In particular, one-passenger ridesharing services add up 2.8 vehicle km on the street per each vehicle km of personal driving removed, and the inclusion of shared services marginally decreased this figure to 2.6 vehicle km added (Schaller Consulting, 2018). The main reason is that most users switch from non-auto modes, including public transport, walking, and cycling. In addition, there is added mileage between trips as drivers wait for the next dispatch and then drive to a pick-up location, and even in a shared ride, a part of the trip involves just one passenger when pick-up locations are different.

However, as it happens with many other trends, it is important to keep in mind that other world regions have very different contexts, and the considerations for Europe or North America may not be applicable. In particular, in large cities without well-developed public transport solutions (e.g., Asia, Africa, South America) ridesharing can provide an economically sound solution for citizens that cannot afford a private vehicle but has the resources to pay for a higher-level service compared to three-wheelers or mopeds. Moreover, other aspects are important in the analysis of the ride-hailing business model, such as the ownership of the vehicles. While in the USA, ride-hailing services are often provided by private citizens with their personally
owned cars, as a part-time activity, this is not the case for other countries, such as India. The cars registered on Uber or Ola (another ride-hailing app) platforms are often owned by large transport contractors that hire drivers, whose earnings are as low as one tenth of those of drivers owning their personal vehicles (Karnik, 2017). However, the investment costs of a new car remain a strong barrier for most drivers, although ride-hailing companies are pairing up with banks to provided dedicated loans. These aspects are of crucial importance for the policy makers that need to assess all the social and economic benefits supplied by ride-hailing platforms to citizens.

### 3.3.3 Carpooling

A better approach for sustainable transport is the concept of carpooling, which aims at increasing the average number of passengers per car by matching users that have the same travel demand. Some carpooling schemes are dedicated to daily commuting to work, which shows a significant potential due to the regular frequency of the trips and to the average car occupancy, which is much lower than for leisure trips, with most car owners driving alone to work. Carpooling has been widely adopted to share the operating costs of travelling by car, with significant benefits related to fossil energy savings, lower CO₂ and pollutants emissions, less traffic on the roads and lower needs for parking spaces.

Whereas carpooling schemes have often been informally organized, mainly between family members or colleagues, the availability of digital platforms to match demand and supply has represented a significant opportunity to increase their diffusion. Digital-driven carpooling has also seen a renewed interest for longer one-off journeys, for which it was harder to find potential matching passengers. In long journeys, carpoolers often join for a part of the trip, giving more attractiveness and flexibility to carpooling and allowing and easier matching between drivers and passengers. Online platforms for carpooling usually use community-based trust mechanisms, such as drivers’ and passengers’ reviews, to increase user comfort and security during the trips.

While all these advantages seem to promote carpooling as a sustainable solution, it should be noted that, like for other transport solution, a key aspect in evaluating its effectiveness lays in the modal shift that is involved in the process. Carpooling is a significant improvement for users that would have travelled with private cars, but when it draws to cars previous public transport users, the benefits are harder to quantify. A recent study has considered the annual operational data of BlaBlaCar, one of the largest web-based carpooling communities, to evaluate its net contribution to CO₂ emissions in selected countries (Butt d’Espous & Wagner, 2019). The results show a positive effect driven by the large increase of average car occupancy rate, which increase from 1.9 to 3.9 in the eight selected countries (it has to be noted that BlaBlaCar provides only trips between different cities, with a very low share of commuting users). The study also considers the actual modal shift of the carpooling
users, thanks to dedicated surveys, and it includes the additional trips that would have not been done if carpooling was not available (representing 5.2% of the members, ranging from 2.8 to 9.6% on a country basis). The study is based on 95.3 million journeys in 2018, and the calculated emissions of carpooling result in 2.2 million tons of CO₂, compared to 3.1 Mt that would have been emitted if carpooling were not available.

While this case represents a very positive example of the possible benefits of shared mobility, the actual modal shift and the additional trips generated remain two key aspects that may undermine the sustainability of other carpooling models. Again, proper policies are needed to help developing an integrated approach to mobility planning and avoid direct competition between public transport and private-based mobility models.

### 3.3.4 Bike Sharing

Bike sharing schemes had a long history, dating back to 1965 in Amsterdam, when citizens organized a system to share free bikes painted in white and made available to users throughout the city. Unfortunately, this program suffered from the lack of dedicated locks that finally made most of the bikes to be damaged or stolen, leading the program to be shut down. Public-based bike sharing schemes took decades to develop, and at the beginning of the century, there were still less than ten systems worldwide. However, the availability of web platforms and the possibility of locating available bikes in real time based on the user location through a smartphone have supported a strong rise in bike sharing schemes in multiple cities worldwide. Furthermore, Internet of things has unlocked the possibility of dockless systems (aka free-floating): since each bike is always connected to the web, thanks to an algorithm it can be locked and unlocked when needed through an app, and it can be left anywhere (or almost) since its position is continuously recorded.

Station-based and free-floating systems represent two distinct models, which have mostly remained separate until now. The former has been generally the result of a choice of each city, with a part of financing provided by public municipalities to foster clean transportation for the citizens. Some systems have been implemented before the digital transition and the diffusion of smartphones, resulting in a bottom-up development of bike sharing systems with the users needing to register to each city separately, often with the need of a physical registration process. Conversely, dockless systems have been deployed across different cities by large companies (mostly Chinese) with a top-down approach, often without a real dialogue with the involved municipalities, and an advantage for the users is that they can access the service in different cities by registering once to the platform. In last years, some hybrid systems are being implemented to try to maximize the advantages for the users.
The bike sharing market worldwide shows a strong expansion, and it is not easy to access updated statistics due to the absence of a common association or data collection standard. The largest amount of bike sharing trips happens in China, where the immense market increase from 2015 has been mainly driven by private players (Roland Berger, 2018) and few public data are available. As of December 2019, the most comprehensive map of existing bike sharing programs across the world (DeMaio, 2019) lists 2120 cities in operation, 368 cities in planning or under construction, and 414 cities that are no longer operating. Another platform (O’Brien, 2019) is performing a real-time tracking of 474 cities worldwide, by exploiting the available data from multiple sources. The service is currently monitoring more than 44 thousand docking stations for 380 thousand bikes, providing detailed information for each city down to the dock level, with historical trends over the last 24 h. Another similar service (Citybikes, 2019) is providing open data information through a dedicated application program interface (API) with live information for more than 400 cities worldwide.

As in other shared mobility modes, the use of data generated by the users is at the center of a business strategy to optimize the operation of the system as well as to provide a better users experience and additional services to the customers (Roland Berger, 2018). The availability of bike sharing operating data, often made available as open data to the public, is a precious resource for policy makers and mobility planners to evaluate the usage of bike sharing in cities, and to plan future improvements as well as verify their effectiveness. In general, bike sharing usage has a strong variation over the day, in line with the usual mobility patterns in cities related to commuting (see the example of the bike sharing of Turin, in Fig. 3.2), but at the same time the seasonal variation related to weather conditions can play a stronger role than for other modes, although with variations from a country to another.

Fig. 3.2 Daily profile of bike sharing use in Turin (based on 5-min data in 2018). Source Noussan, Carioni, Sanvito, and Colombo (2019)
3.3 Shared Mobility—Sharing Assets or Trips?

Bike sharing has proven to be an effective solution especially for first- and last-mile trips, often coupled to public transport solutions. The growing ecosystem of integrated mobility solutions, driven by MaaS platforms, can further support the evolution of bike sharing, thanks to its potential in supporting the choice of public transport, to discourage the use of private cars when they are not necessary.

In some cases, bike sharing is being equipped with electric bikes, which provide the users with a more convenient solution, especially in cities with hilly terrain. The use of e-bikes generally requires an extra fee for the users, and attention needs to be paid to the charging infrastructures of e-bikes to ensure a proper user experience. The integration of e-bikes in existing station-based bike sharing systems often required the upgrade of the docking stations to allow for the charging of batteries.

3.3.5 Electric-Powered Micromobility

Another phenomenon that is showing a considerable hype in the US as well as in major European cities is the deployment of electric-powered micromobility, notably electric scooters. While bike sharing systems involve the use of a transport mode that has a long history and thus specific rules for its operation over roads, many countries and cities are still facing the need of developing proper regulations for electric scooters, which thus remain in a gray area in many cities and states/countries. Different companies have exploited the lack of regulation to deploy their e-scooters in cities, but in some cases, they have been subsequently forbidden to operate (e.g., San Francisco), due to issues including improper scooter parking on sidewalks and low availability of scooters in low-income neighborhoods.

The story of electric scooters sharing systems starts in the USA, where they have shown a massive deployment in the last few years, with total e-scooters trips in 2018 reaching a value of 38.5 million, higher than the 36.8 million trips of station-based bike sharing systems (NACTO, 2019). As of the end of 2018, the number of e-scooters available in about 100 US cities was over 85,000, but 40% of all e-scooter trips took place in the Los Angeles, San Diego, and Austin regions. These e-scooters have almost totally substituted the use of dockless bike sharing systems, with the notable exception of Seattle, since different bike sharing operators have shifted their focus on e-scooters by retooling their fleets (including Lime and Spin).

An analysis in some US cities on usage patterns and profiles (NACTO, 2019) showed that e-scooters users are more similar to casual bike sharing users that to annual subscribers, the latter using bikes to commute and thus in morning and evening rush hours. Conversely, riders are using e-scooters for different purposes, including social, shopping and other recreational activities. For the same reason, e-scooter ridership shows higher interest during weekends than during weekdays. E-scooters are usually more expensive than bike sharing or e-bikes, with the average trip in 2018 costing to the user 3.50$ to travel little more than 1 mile in roughly 15 min. Thus, many cities have requested the companies to provide discounts to low-income citizens to support a more equitable access to mobility options in the US cities.
The huge use of e-scooters for occasional and very short trips suggests that they have involved a modal shift from other active modes, mostly walking and cycling. Thus, the use of e-scooters involve an additional electricity consumption, together with the need of moving the e-scooters to charging stations at night and then back to the streets at early morning. While the electricity consumed may be produced by renewables, the gasoline burned by the vans used to move the scooters overnight is not. For this reason, the use of e-scooters may not be classified as a sustainable mobility option, unless a better integration with other modes and alternative charging strategies help demonstrate real benefits. On the other hand, it is always important to remember that while sustainability is an important aspect, the supply of additional services to the citizens (including faster and more convenient mobility options) should be in some way accounted for in a systemic perspective that goes beyond the simple evaluation of the energy consumption.

Besides the USA, e-scooters are being deployed in several European cities by different private companies, and the available market reports expect a very strong potential in Asian countries in the next decade, which may represent the largest share of e-scooters sales by 2030.

3.4 Autonomous Vehicles—Would You Bet on It?

Among the different innovations that are currently fostered by digital technologies, self-driving vehicles represent at the same time the less mature and the one with the highest disruption potential. The passenger transport of the last century has been mainly centered on private cars, thanks to the high flexibility and convenience of driving. At the same time, everyday mobility is also characterized by frequent congestions, especially in large urban areas, leading to waste of time, environmental impacts, and safety issues. Autonomous cars may strongly enhance the travel experience of passengers, by providing an even higher degree of flexibility without the need of staying behind the wheel. In fact, passengers may dedicate to a large variety of activities during travels, and the time that is currently wasted can be exploited for working or entertainment. Moreover, the time required to find a parking spot in the city center will no longer be needed, and fleets of shared AVs may continuously remain in movement, based on optimization algorithms that coordinate their paths based on the users’ demand.

The key aspect supporting the deployment of AVs is the enhanced safety of road transport, since a total shift toward self-driving cars may remove all the accidents caused by human errors. AVs can also guarantee a smoother operation, with more efficient driving cycles and a better coordination with other vehicles leading to fewer congestions. Still, the interaction between computer-driven cars and human-driven cars (or bicycles, pedestrians, animals) may be less easy to manage, since humans are much less predictable, and the absence of eye contact may lead to difficult interactions between humans and robots. Thus, the transition phase toward the use of AVs may
prove to be even more complicated, and potential issues may also discourage people to move away from their current traditional cars.

Autonomous cars are usually classified based on the level of automation that they can provide, on a scale from level 0 (no automation) to level 5 (full automation). These levels represent a gradual increase of the tasks that are carried out without the manual intervention of the driver, including accelerating/decelerating and steering, but also the range of conditions in which the car can handle an autonomous operation, with particular attention to weather issues, such as rain and snow. While a full automation needs to handle a wide range of aspects, a partial automation has the additional issue of managing the interaction with the driver, and the switch of controls between car and driver. In particular, the driver may be asked to intervene in emergency situations, but his reactivity may be strongly penalized if he is not already paying attention to what is happening around them.

Research and development of AVs require huge investments, and automotive companies are often developing joint projects with other competitors to share the efforts and the potential risks. Many IT companies are also developing their own solutions, by exploiting their know-how to define proper algorithms and control systems. Two opposite strategies are possible to reach the full automation, either by heading directly toward level-5 automation, or by adding gradual levels of automation. The former strategy involves higher technical barriers and may require waiting a long time before producing a commercial car, while the latter allows to monetize each additional improvement by continuously upgrading the commercial vehicles on the market. However, this slows down the entire process, and focusing too much on single improvements may lead to never reaching the final goal.

The operation of AVs requires a huge amount of data collection and elaboration, both from onboard sensors and from a continuous communication with other vehicles (vehicle-to-vehicle, V2V) or with the external infrastructure (V2I). Thus, a significant improvement of mobile data infrastructure will be required, since the deployment of connected cars will lead to a quick exponential increase of data flow. Each data communication will also need to face issues related to privacy concerns and potential cybersecurity threats. Moreover, the onboard hardware and software solutions will need to be able to handle increasing amounts of data, which will increase by orders of magnitude. Today a connected car, even at a low degree of autonomy, is generating roughly 25 GB per hour. These numbers can rise to between 1.4 and 19 TB per hour for an autonomous car, depending on the sensors setup (Dmitriev, 2019).

Apart from the technical aspects, the development of AVs will also involve ethical issues. Since the AVs operation will be based on human programmed algorithms, in the eventuality of an unavoidable collision with pedestrians, the car needs to be programmed to choose whether to protect the passengers onboard or the pedestrians outside. While human drivers often react in an unpredictable way in emergency situations, AVs will just apply precisely the set of rules that they have been taught. It will not be trivial to reach a consensus on these ethical issues, especially considering the huge variety of situations that may occur. Moreover, different cultures may have different approaches and opinions on what is ethical and what is not. Finally, in the event of an accident involving AVs, it is not clear who will take responsibility for it:
national laws as well as insurance companies’ regulations will need to be modified to handle these potential situations.

Given all these issues and opportunities, a large uncertainty remains on the eventual effect of AVs on the energy consumption and the environmental impacts of the mobility system. The automation of vehicles may improve driving cycles with strong benefits for fuel economy, and the potential reduced congestions will also increase the system efficiency. However, these may be outpaced by a strong increase in demand driven by the high quality of travelling in self-driving cars, even by people that are currently using public transportation. Moreover, a group of people that are not able to drive (children, elderly or impaired) may grant access to mobility and create additional demand. The higher productivity during travel may also decrease the issues related to commuting time, pushing the people toward an even increased urban sprawl to benefit from lower housing prices far from city center.

One of the key aspects for energy consumption will be the ownership model, and in particular, if AVs will be privately owned or shared. A private autonomous car will be more similar to the use of the car we have today: we are able to choose the model we prefer, we can store items in it and in some cases it represents a status symbol. On the other hand, it will end up in being much inefficient, just as today’s cars: it will necessarily involve a significant amount of empty trips to look for a parking when not needed, and it will still be useful for a very limited amount of time. Conversely, a fleet of shared AVs may be more effective in optimizing the mobility demand of different people, with the possibility of also sharing trips with other passengers. Empty vehicles may be kept in motion, waiting for other passengers requesting a vehicle. However, while this may decrease the need for parking in city centers, loading and unloading zones will still be needed, and the continuous traffic of empty vehicles nearby popular locations, required to ensure a timely response to people’s mobility demand, may end up to be a backlash for both safety and environment. Users’ behavior and mobility patterns will remain at the center of effectiveness of shared travels. While AVs may provide optimized solutions for occasional mobility, the systemic travels, and especially commuting, are harder to improve. Today’s mobility demand in cities is often characterized by strong peaks both in the morning and in the evening, caused by commuting trips. Without any major changes, AVs will provide little benefits for congestion, unless people accept to share the vehicles with other passengers.

Nowadays, there are many companies involved in testing autonomous vehicles worldwide, and although there are still no commercial vehicles able to provide full autonomy, some companies are testing full-autonomous ride-hailing services (although with safety backup drivers, in some cases also due to regulatory issues). Testing phases in real conditions are necessary to evaluate the response of algorithms in a wide range of cases that is difficult to predict and replicate in lab. Vehicle test is also important for users, which need to experience the actual behavior of riding a self-driving car.

Finally, while much attention is given to autonomous cars, another interesting application is related to autonomous trucks. Its implementation may be easier, especially in dedicated environments, since their operation is much more regular. The
automation of road freight transport may provide significant fuel savings through platooning, i.e., the possibility of driving vehicles together with a minimum distance between each other, thus reducing the air resistance and also increasing the trucks density in highways.

3.5 Data-Driven Mobility Planning

An additional aspect to be discussed is the possibility of exploiting the available data generated by different mobility modes to improve the urban planning. Data can be sourced from a wide range of devices, both related to vehicles (e.g., car sharing, micromobility vehicles) or to users (mainly through smartphones applications), and they can be fitted to different applications. Available data from different shared mobility models can help local planners, as well as company managers, to optimize the distribution of available vehicles in the city neighborhoods, to ensure the highest access to mobility through different classes, especially for micro-mobility options. On the other hand, useful data from smartphones can help to build up reliable models for congestions management and analyze the behavior of people through different modal shares, which can be estimated from the average speed and other aspects related to each trip (such as the number of people sharing the same positions over time, the matching with available public transport schedules, etc.).

In some cases, private companies can provide a support to local communities in transport planning, by sharing their data on users’ behaviors and mobility patterns. The use of mobile phones data to support transport planning has seen a dramatic rise in the last decade, with the result of improving the accuracy of the transport monitoring and modelling. Moreover, while these data are generally unable to provide detailed information on the transport mode which is being used, data from specific applications may provide additional insights. An example is the use of fitness apps that register the route of runners and bike riders to evaluate the actual demand for mobility. One of those apps, Strava, has already supported local mobility planning in more than 300 communities, including Portland and Seattle, by exploiting the data provided by more than 45 million users to evaluate the effect of different mobility choices, such as estimating the effect of different bike lanes layouts (Andrews, 2019). Data are provided only to organizations that plan, own or maintain infrastructures, and a proper data aggregation is performed to avoid privacy issues.

However, there are also cases where the problem of data ownership arises, especially if those data represent a significant business value for a company against its competitors. This is often the case for shared mobility players, whose operating data may represent a very valuable resource for urban planners. While there are usually few national regulations, cities are starting to implement specific actions to try to take advantages from available data. One notable example is the Mobility Data Specification, or MDS, an open-source digital tool initially developed by the city of Los Angeles, USA, as a standardized way to collect operational data from dockless e-scooters, bicycles, and car share (Open Mobility Foundation, 2019). This set of
Digitalization interfaces has been developed to help the dialogue between shared mobility companies and municipalities, since currently each site was requiring a different standard with a lack of efficiency for operators. However, some firms, including Uber, are raising concerns about the potential privacy issues for dockless vehicles users, since there is currently no clear statement on the circumstances under which data can and cannot be shared with other agencies requesting it (Zipper, 2019). The central point is whether local planners should receive raw operation data on each single trip of the users, or rather be able to access aggregated data only. Although single trips can be anonymized, research studies claim that even with anonyme data almost each individual can be identified with as little as four space-temporal data points (de Montjoye, Hidalgo, Verleysen, & Blondel, 2013). Effective solutions to ensure users privacy will be crucial for the success of data-driven planning, either by choosing the right level of data aggregation or to ensure a restricted access to those data.

While much focus is on passenger transport, also freight transport can exploit the availability of new datasets to optimize logistics and match the goods demand in the most efficient way. Data related to vehicles, cargoes, drivers, companies, and infrastructures can be used to increase operational experience and to enhance customer experience, and new business models can be created by expanding revenue streams from existing products or by creating new data-driven products. There is a growing trend in companies to exploit digital technologies to try to anticipate consumers’ needs, based on a wide variety of historical data collected from customers’ behavior. A notable example is the concept of “anticipatory shipping,” a patent filed by Amazon in 2013, which involves the shipment of a good before a customer even buys it (Bensinger, 2014). This method, based on machine learning algorithms trained on different data trends, may lead to a significant decrease of shipping costs, since standard shipping is usually much cheaper than two days delivery, but also to a significant increase of customers’ experience resulting in higher brand loyalty.

3.6 A Final Look at Digitalization Outside Transport—What Will It Change?

As we saw in the previous sections, digital technologies are enabling multiple mobility solutions, and the future potential is even more significant. In addition, there are also many applications that are outside the conventional boundaries of the transport sector, but which may have significant impacts on mobility demand patterns. Think about the possibility of remote working and the virtualization of goods that can be used without the need of a physical copy shipped to our home (books, music, movies, etc.). These technologies may decrease the mobility demand of workers and goods, lowering the total energy consumption of transport. E-commerce and food deliveries may have a more complex effect on transport, since they involve a shift from passenger to freight mobility, by decreasing some shopping and recreational activities but at the expense of an increase of urban deliveries.
However, while some digital technologies decrease the mobility demand and thus the consequent energy consumption, they require a significant amount of energy to operate the web infrastructure that supports their services. Thus, an energy consumption decrease in transport sector may be compensated or even outweighed by an increase of electricity demand for the entire supply chain of movies or music streaming. Watching a one-hour movie on Netflix causes 3.2 kg of CO$_2$ emissions (The Shift Project, 2019), which is more than driving 25 km with a new car. Online video streaming is showing an exponential increase each year, and in 2018 it was responsible for 306 Mt of CO$_2$ emissions, a little less than 1% of total emissions. The trend is expected to continue, since more and more people are accessing these services, and the video quality (i.e., amount of data) is continuously increasing to provide better user experience on larger devices.

The effect of e-commerce is less clear, and different research works conclude that there is no trivial answer at the positive or negative effect of buying things online rather than driving to the mall. Some analyses remark that shopping is seldom the sole objective of a journey, and people combine the need for buying goods with other recreational activities. Thus, lower shopping needs would not directly correlate to a corresponding decrease of mobility demand. Conversely, e-commerce is leading to an unprecedent need of last-mile deliveries in urban environments with commercial vehicles, worsening congestion, local pollution, and fuel consumption (and thus emissions). The one-day or one-hour deliveries push for even higher presence of delivery services nearby the users. And e-commerce may actually increase the total amount of consumed goods, rather than just shifting habits from mall to online shopping.

However, there is still room for optimization, and large companies are exploiting the availability of huge amount of data to discover online buying patterns that may help them predict the future behavior of customers. Amazon has filed a patent on the concept of “anticipatory shipping”: the idea of starting to ship any good before the customer buy it (Bensinger, 2014), to cut on delivery times and costs, since slow deliveries cost much less than fast ones. This could even go further, sellers may ship to customers goods that they may like, with the possibility of shipping them back. The efficiency may not seem to be high, but the business model may work, depending on the accuracy of the algorithms and on the additional effort required to customers to ship back a good that they may wanted to buy sooner or later.

As for other digital technologies, the potential of demand increase competes with the potential of a larger efficiency supported by optimization algorithms. It is difficult to predict which trend will prevail over the other, and probably, there will be differences across sectors, regions and times. Any analysis on transport impacts may require a system perspective, since digital technologies are shifting consumption beyond the traditional borders of what we considered to be the transport sector. The transportation of people and good is gradually and partially being shifted to the transportation of information through virtual networks, and this phenomenon needs to be factored in when looking for the future of mobility.
3.7 Conclusions and Key Take-Aways

This chapter depicted a brief synthesis of the main aspects related to digital technologies in transport, by discussing the current state of the art and the possible future evolutions. Digitalization has the potential of becoming a game changer in different sectors, from shared mobility to autonomous vehicles.

At the same time, digitalization interacts with other mobility trends, and the future effect on the demand for transport and the modal share of travelers is far from being clear. The adoption of various solutions will have a large variability from a country to another, and their success will be based both on their capacity to deliver convenient and reliable services to customers at a lower cost, and on their sustainability in terms of environmental impact at local and global scale, urban traffic and safety aspects. Policies and regulations will have a crucial role in fostering the deployment of effective solutions based on available technologies.

Digital technologies are already demonstrating their potential in fostering the use of public transport and shared mobility options, by providing the users with live alternatives for their trips and by supporting the planning and operation of urban transport systems thanks to a wide collection of measured data. Collective transport may decrease the number of private cars on roads, especially in urban environments, leading to fewer congestions, lower need for parking space, better air quality in city centers. These aspects will be more and more important as urban population is continuously increasing worldwide, with the need of a complete rethinking of urban planning to accommodate the related mobility demand of citizens.

A pivotal aspect for future transport systems and models will be the evolution of autonomous vehicles. The effectiveness of AVs still needs to be demonstrated, and in addition to technical aspects, the technology needs to face users’ confidence and willingness of adoption and ethical issues related to potential accidents. Finally, even if AVs can reach a significant penetration level, it is not clear if their operation will lead to an optimized use of available vehicles or if they will just increase the total mobility demand and thus the congestion. Policies and regulations will prove to be central in driving a sustainable use of AVs.

A final remark is that digital technologies are not necessarily supporting a more sustainable transport system, although their potential is interesting. Like any other technology, they provide additional opportunities for users and for companies, but their deployment needs to be matched by timely and accurate policies that support a sustainable transport planning by defining clear and achievable targets.
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