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Review

How Can Autonomous and Connected Vehicles, Electromobility, BRT, Hyperloop, Shared Use Mobility and Mobility-As-A-Service Shape Transport Futures for the Context of Smart Cities?

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Abstract: A smarter transport system that caters for social, economic and environmental sustainability is arguably one of the most critical prerequisites for creating pathways to more livable urban futures. This paper aims to provide a state-of-the-art analysis of a selection of mobility initiatives that may dictate the future of urban transportation and make cities smarter. These are mechanisms either recently introduced with encouraging uptake so far and much greater potential to contribute in a shift to a better transport paradigm or still in an embryonic stage of their development and yet to be embraced as powerful mechanisms that could change travel behaviour norms. Autonomous and connected vehicles are set to revolutionise the urban landscape by allowing machines to take over driving that for over a century has been exclusively a human activity, while electrical vehicles are already helping decarbonising the transport sector. Bus rapid transit has been steadily reinventing and rebranding conventional bus services revitalising the use of the humblest form of public transport, while hyperloop is an entirely new, disruptive, and somewhat provocative, travel mode proposition based on the use of sealed tube systems through which pods could travel free of air resistance with speeds exceeding 1000 km/h. Shared use mobility mechanisms like car-sharing, ride-sharing, ride-sourcing and public bicycles can help establishing a culture for using mobility resources on an as-needed basis, while mobility-as-a-service will take this sharing culture a step further, offering tailored mobility and trip planning packages that could entirely replace the need for privately owned modes of transport.

Keywords: urban transport; transport futures; smart cities; autonomous and connected vehicles; electric vehicles; bus rapid transit; hyperloop; shared use mobility; mobility-as-a-service

1. Introduction

Smart cities are the result of knowledge-intensive and creative strategies, aimed at enhancing the socio-economic, ecological, logistic and competitive performance of cities [1]. This, from a transport perspective, implies that any urban environment looking to be classified as a smart city, should respond effectively, among others, to the dual mobility challenge, as defined by [2], of rapid urbanisation and growing traffic congestion. The way to address this obstacle is by conceiving, designing and delivering a transport system that provides socially inclusive, environmentally friendly, safe, cost-effective, integrated and technologically informed travel options to road users that enable them to reach their preferred destinations with ease. Transportation is, therefore, one of the most fundamental aspects of the modern society [3], a key enabler of the many other notions that define and characterise a smart city and a powerful indicator of future prosperity.

The present article has not a prophetic character per se. Predicting the future is by definition a complex and uncertain procedure; it is more dark art than science especially when technological breakthroughs, which are even harder to predict, can take transport to completely different avenues. Instead, our work discusses a specific vision of tomorrow's transportation based on an integrative literature review that examined some key thriving, but not yet universally embraced, current transport initiatives and some future ones that have been publicly demonstrated through piloting. The choice of the mobility interventions discussed, although is subjective and directly referring to the authors' expertise and interests, is based on potential impact considerations; all of these mobility mechanisms, if widely embraced, can reshape transport, others with softer approaches, rebranding, complementing or integrating already existing services and others with a harder approach transforming current thinking. The core sections of the paper, followed by a discussion and conclusions part, present the six chosen interventions namely: autonomous and connected vehicles, electromobility, bus rapid transit, hyperloop, shared use mobility and mobility-as-a-service.

Autonomous and connected vehicles (ACVs), the developing crown jewel of the synergies between artificial intelligence (AI), robotics, automotive design and information technologies, have the potential to be the most robust intervention in the history of mobility by empowering the car to take control and perfect the craft of driving, making calculated decisions and interacting with the urban environment and traffic flow to heights unprecedented for a human. In theory at least, fully connected driverless vehicles have the capacity to transform urban development as known today, with a revolution in ground transport, regulations permitting, that could dramatically change the landscape of cities and have an enormous economic, social, spatial, and mobility impact [4].

The future of oil economy, which in large depends on conventionally fuelled vehicle fleets is not only unsustainable but also very limited. In contrast, the electrification of the transportation sector appears to be one of the feasible solutions to challenges such as global climate change, energy security and geopolitical concerns on the availability of fossil fuels [5]. Therefore electric vehicles (EVs) may have a critical role in how smart cities become more energy-efficient and less polluted.

Bus rapid transit (BRT) is a mobility revelation, of South American origin, that already prospers in 164 cities across the world. BRT means to transform buses, the humblest of the public transport modes, to a genuinely attractive travel alternative. BRT refers to schemes that apply rail-like infrastructure and operations to bus systems in expectation of offerings that can include high service levels, segregated right-of-way, station-like platforms, high quality amenities and intelligent transport systems for a fraction of the cost of fixed rail [6]. Thus, by integrating facilities, services, and amenities catering, in theory at least, for the shortfalls of conventional buses, BRT can be competitive to car-oriented mobility, to the degree that it could redefine the very identity of a city by claiming space for the upgrade of the city's public transport service provision.

Hyperloop is the most ambiguous of the transport initiatives presented in this article; an idea that has been scarcely piloted until now that aims to re-invent ground public transport offering services travelling at faster speeds than commercial flights. Hyperloop is projected to use magnetically-levitated pods running inside tunnel systems free of air resistance. Despite its potential merits Hyperloop is still widely considered as a futuristic disruptive transport mode that may supplant current mobility service constructs [7] instead of complementing them.

Shared use mobility (SUM), a concept aligned with the grander notion of sharing economies, is a way of rethinking and repositioning transport on the urban landscape. Rather than individual physical items being purchased, owned, controlled, maintained and used solely by their owner, in SUM systems the physical assets (cars, bicycles, vans, motorbikes, etc.) are accessed sequentially by multiple users on a pay-per-use basis [8]. There are already thousands of bike-sharing, car-sharing, ride-sharing and ride-sourcing schemes across the world but despite their merits, are widely perceived as first- and last-mile complements, tourist or visitor services, trip-to-work commuting initiatives and alternative taxi mechanisms respectively and not complete transport solutions.

Mobility-as-a-service (MaaS), a newly-born transport initiative with limited implementation thus far, is a more radical solution that replaces privately owned transport and optimises the use of mobility resources. MaaS platforms typically provide an intermodal journey planner (providing combinations of different transport modes: car-sharing, car rental, underground, rail, bus, bike-sharing, taxi, etc.), a booking system, easy-payment, and real-time information [9].

2. Autonomous and Connected Vehicles

Over the last two decades the automotive industries have made momentous leaps in bringing computerisation into what has, for more than a century now, been exclusively a human function: driving [10]. Advanced driver assistance systems (ADAS) equipping vehicles with more computational power, improved safety features, navigation systems and other driver-experience enhancing mechanisms including adaptive cruise control, collision avoidance system, auto-parking, lane warning, emergency driver assistance, intelligent speed adaption, adaptive light control, night vision, anti-lock braking system have been already launched and are becoming standard features for high-end cars at least. These features, although slowly diffused since, because of their isolated and incremental nature, they do not represent a substantial upgrade for the overall service equivalent to that linked with a full-scale implementation of autonomous technology, constitute the first real evidence of a future where car-oriented mobility could be machine-led. Pilots of entirely autonomous, but still humanely supervised, cars are being tested in testbeds across the world meaning that road vehicles capable of operating independently of real-time human control under an increasing set of circumstances will likely become more widely available [11] and be at the very heart of a smart city's transport system.

Autonomous vehicles (AVs) also known as automated, driverless, self-driving, robotic vehicles are projected not only to take over the task of driving per se but to have another meaningful power; the capacity to interact and eventually 'synchronise' in real-time with all the elements and actors of the transport network including other vehicles and road transport infrastructure. Connected vehicle technology will provide real-time information about the surrounding road traffic conditions and the traffic management center's decisions improving efficiency and comfort while enhancing safety and mobility [12]. This section of the paper will primarily concentrate on vehicles with the dual capability of being autonomous and connected (ACVs), better known as connected and autonomous vehicles (CAVs), and not semi-autonomous or partially connected vehicles, since the former represent the most likely and impactful way of adopting AV technology in the future.

2.1. The Potential to Impact Transport Futures

CAVs are anticipated to be the next golden standard of mobility, transforming smart urban growth as conceived today, with a transport revolution that would radically change the very identity of cities by impacting every facet of urban living. CAVs introduce numerous different benefits, from substantially reducing traffic accident rates, road congestion, social exclusion for those currently unable to drive, noise nuisance and carbon emissions but also some concerns about increased vulnerability to hacking, software and hardware flaws, loss of privacy, liability allocation, rise in user numbers, behavioural adaption and user resistance problems [13–16]. CAVs have been also associated with the negative socio-economic consequences of the loss of millions of driving-related jobs [17] although there are studies [18] reporting that there are many transport experts who believe that human ingenuity will create new jobs, industries, and ways to make a living, just as it has been doing since the dawn of the Industrial Revolution. This will prevent the displacement of significant numbers of blue- and white-collar workers. If these jobs are not to be replaced this could lead to masses of people who will be effectively unemployable, immense increases in income inequality and breakdowns in the social order at least in a short-term basis.

CAVs may also have the ability to generate new opportunities for integrated services for two other major transport initiatives that are critical for the future of smart cities because of their ability to promote more resource-efficient mobility patterns than private cars; public transport and shared use mobility mechanisms. The incorporation of CAVs in the fleets of public transport and shared use mobility schemes will completely change their focus, the way of operating, managing and regulating the services they provide and their marketing and branding strategies. Combining CAVs with electromobility concepts, making these vehicles more inexpensive to use in environmental, economic and social terms would improve their energy consumption efficiency and cost-effectiveness. As [19] explicitly suggests the synergistic effects between vehicle automation, sharing, and electrification can multiply the benefits associated with those three transport initiatives.

2.2. The Current State of Development

Autonomous car technology is already being developed by many leading automotive manufacturers that want to create the narrative for the forthcoming transformation and be in an advantageous business position in the future, by ride-sourcing providers that want to replace human labour with cheaper self-driving apparatus, and information and communication giants that see this as a monumental opportunity to expand their services into and eventually dominate a new technology-driven arena. Some of these companies joined forces forging partnerships and alliances that will allow them to surpass the multi-dimensional challenges that CAVs now pose to their developers. The key competitors so far, that have heavily invested on this new frontier and are now beyond an early-stage exploration of the concept, with some of them being responsible for thousands or even millions of autonomously driven miles, in alphabetical order are: Audi, Baidu, BMW, Daimler, Delphi, Didi Chuxing, Ford, General Motors, Honda, Huawei, Hyundai, Jaguar Land Rover, Lyft, Magna, Mercedes-Bosch alliance, Microsoft, nuTonomy, PSA, Renault-Nissan alliance, Samsung, Tesla, Toyota, Uber, Volkswagen Group, Volvo, Waymo (Google's self-driving cars project), ZF and Zoox.

Autonomous cars are already piloted in California having humans inside them at all times. There is, however, enough political determination to make a leap forward so it is expected that California will be changing regulations for self-driving cars to allow their unsupervised use in the next few years. Volvo's Drive Me project, will put a fleet of 100 autonomous vehicles in the hands of everyday drivers with the promise that they will not need to continuously supervise the vehicle operation. These vehicles will be tested on public roads in Gothenburg, Sweden as a means of defining and evaluating how AVs impact the quality of life and the urban environment [20]. At the same time the UK Government is dedicating financial resources for creating the world's most effective CAV testing ecosystem by building a number of distinct test capabilities. This is an investment that the Government believes will cement the UK's status as the go-to destination for development of CAV technology [21]. Similarly, New Zealand Transport Agency supports manufacturers and developers wanting to test AV technologies ensuring testing requirements that are easily navigated, and testing processes that keep both the public and testers safe [22]. The Australian Driverless Vehicle Initiative is an effort to explore the impacts and requirements of CAV technology and make recommendations on ways to safely and successfully bring self-driving vehicles to Australian roads [23]. Finally, Horizon 2020, Europe's leading framework for funding research and innovation, has devoted thus far €239m for autonomous car technology [24] and the internet of things (IoT) [25], which is the equivalent of the AVs' connectivity backbone.

2.3. Barriers to Overcome

Despite this colossal amount of investment and interest in the development and uptake of CAVs, the reality is that a full-scale launch of CAVs is not imminent; it is likely to happen later than most expect. There are many obstacles that stand in the way of a full-scale introduction.

1. Technology is still lacking; despite serious progress more breakthroughs are necessary for supporting such an unparalleled mobility paradigm shift. CAVs need to go beyond correctly

detecting and identifying objects in typical transport scenarios; they need to able to anticipate their behaviour even under the most complicated and unexpected circumstances.

2. Despite some initial efforts to address it, legislation could be a barrier; road traffic regulations, liability allocation and enforcement strategies need to incorporate the use of CAVs.
3. Although recent studies showed that *a priori* acceptability of CAVs could be likely for many drivers today [26,27] the universal acceptance of such a transition is not guaranteed or certain [15]. Users might need to be convinced.
4. The implementation of CAVs, will not be straightforward, predictable, unproblematic or without risks; there is a wide spectrum of social dilemmas that may arise from such an untested, disruptive and robust intervention [14,16]. Motor vehicles will need to operate responsibly and replicate or do better than the human decision-making process; but some decisions are more than just a mechanical application of traffic laws and plotting a safe path [28].
5. Ethics is an issue that has not been resolved. Even when it becomes possible to programme decision-making based on moral principles into machines, will self-interest or the public good prevail? CAVs will sometimes have to choose between two evils, such as running over pedestrians or sacrificing themselves and their passengers to save the pedestrians [29] and there is not yet a clear pathway of what is the 'right' option.
6. Situational awareness, connection and engagement need to be guaranteed for users. The passive human role when 'driving' CAVs may not allow users to build an appropriate mental model of the situation that is essential for the recovery of system failure [30] and may also lead to disengagement and discontent [31].
7. CAVs cannot properly function in today's road network; they need a friendlier road transport infrastructure that provides them with an environment fit for their use. A lot more capital investment is necessary at this end.
8. Mixed traffic situations, where CAVs share road space with partially automated and conventional man-driven vehicles could create more problems than the ones they are going to solve. There needs to be a plan of how to address the transition from human-led to machine-led vehicles.
9. There is a risk of creating a two- or even a three-speed world; countries and cities' progress in developing and introducing CAV technology may come at different rates and times. This will create imbalance, confusion and disharmony when transport's definitive role is about integration and interoperability.
10. Business models for supporting the CAVs adoption process and the need for synergies with (or incorporating) other transport initiatives are not clear yet.

Introducing AI to vehicle technology will be an unprecedented achievement in the history of road transport revolutionising mobility for ever and shaping the future of societies but for now CAVs are still more of an enigma than a definitive solution.

3. Electromobility

Typical Electric Vehicles (EVs) include means of transportation that are electrified and powered through batteries. The main difference of EVs over conventional vehicles is the fact that they utilise electricity rather than traditional fossil fuels. EVs do not cause any direct CO_2 emission during operation [32], reduce the substantial, long-term increasing fuel costs as well as radiated noise [33] but their high private costs, despite the fact that their owners do not need to pay carbon-related taxes, might hinder their market development [34]. EVs, although still at a relatively early phase of commercial development, vary significantly both in size and technology used. As far the urban environment is concerned, EVs used inside cities mainly include electric cars, low-speed electric vehicles (also known as neighbourhood electric vehicles NEVs), and various types of two-wheelers. EVs of larger scale include electric vans and trucks as well as electric busses. The present section focuses on the road transport for people, therefore electric rail-based transport (e.g., tram, underground) and heavy good vehicles (HGVs) are beyond the scope of the present analysis.

3.1. Electric Cars

The car manufacturing industry has gradually increased its investments for research and development for electric cars rather than conventional ones powered by internal combustion engines. With electromobility presently representing a niche market several companies, including among others, BMW, Bolloré, Chevrolet, Citroën, Fiat, Ford, Honda, Hyundai, Kia, Mercedes-Benz, Mitsubishi, Nissan, Peugeot, Renault, Smart, Tesla, Volkswagen, have announced mega-projects that aim to support this transition.

The main type of electric passenger cars is the battery electric vehicles (BEVs). BEVs are fully powered by locally-contained batteries that are charged by an external energy source. Hybrid electric cars combine the electric engine with a conventional combustion engine at a degree of hybridisation that varies among different models. Plug-in hybrid cars (PHEVs) can be charged directly from the power grid, and accordingly they rely mainly on electricity. The remaining hybrid-electric vehicles' categories (i.e., parallel, mild) are not considered as fully electrified vehicles as they are heavily dependent on their conventional combustion as the main source of propulsion, while electric engines are only complementary power sources.

The leading nation in the utilisation of electric cars is Norway; the Norwegian fleet is possibly the cleanest and arguably the largest per capita in the world. This is the result of generous tax-relieving policies to increase the sales and use of EVs. The typical Norwegian electric car user is a middle-aged family father with higher education and income, who owns a Nissan LEAF as one of two cars, drives his electric car on a daily basis because this saves him money and time and although satisfied with his choice highlights longer range and predictable EV policy as two areas for improvement [35]. Nevertheless, this subsidy policy, implying very low costs to the electric car owner on the margin, probably leading to more driving at the expense of public transport and cycling, is according to [36] counterproductive, needs to change and should not be replicated by other countries. This illustrates the need to utilise the electric car's vast potential in a way that does not undermine the importance of true car alternatives.

3.2. Electric Buses

Bus transit systems with electric traction are an important contribution in the future of mobility since they can overcome the existing disadvantages of conventional buses using fossil fuel [37] and support a push for modal shift to public transport. Electric bus fleets can be emission-free, easy to integrate into an existing infrastructure, ecological and customer-friendly but according to [38] due to their expensive technology, lifecycle costs can be much higher in comparison to diesel or hybrid buses, for now at least. The selection process of electric technology is highly sensitive to operational context and the energy profile of the city host but recent research [39] highlights that hybrid buses, due to their significantly lesser capacity to reduce greenhouse gas (GHG) emissions would be suitable only for short-term objectives as a stepping-stone towards full electrification of transit. Overnight battery electric bus is advocated as the most suitable solution going forward. The electric bus innovation diffusion could be aided by the adoption of new risk management strategies, institutional structures and business models that go beyond traditional measures like subsidies [40].

3.3. Neighborhood Electric Cars

NEVs are generally small electric cars that stand between EVs and electric two-wheelers. The increased market interest, especially in the heavily populated urban cities of emerging economies, has increased the interest on NEVs. NEVs sales in 2016 were between 1.2 million and 1.5 million, and the annual sales' growth since 2014 is 50% [41]. NEVs maximum speed is regulated to an upper limit that depends on the country and is usually between 40 km/h and 70 km/h. Their small power and short range are adopted to the urban needs for agile transportation over short distances and easy parking. Additional advantages of NEVs are their low cost and favourable regulation (e.g., no requirements for driving license or insurance).

3.4. Electric Two-Wheelers

Electric two wheelers are two-wheeled means of transportation with an electric motor. In many aspects they are similar to regular bicycles, but are equipped with an electric motor for propulsion. Moreover, they are equipped with a battery pack that powers the motor. They are mainly distinguished to electric bikes (e-bikes) and electric motorcycles (mopeds). As far as the e-bikes are concerned a great variety of them exists worldwide. This variety extents from pedelecs with a small motor that only assists the user to more powerful e-bikes that resemble the capabilities of a conventional scooter or motorcycle. Generally four main categories of electric two-wheelers exist: pedal assist e-bikes, throttle control e-bikes, speed pedal assist e-bikes and electric mopeds [42]. Electric two-wheelers despite their obvious merits in terms of flexibility and cost-effectiveness can also travel further on less electricity and can be fully recharged in a relatively short amount of time when compared to bigger EVs.

3.5. Electromobility as a Mechanism for Tranforming Transport and Cities

Shifting towards electromobility is an approach that gains an increasing support, especially in cities. EVs are locally emission-free and therefore an important tool to solve air quality and pollution challenges. Moreover, as the electric energy power mix changes and moves towards electricity production from cleaner sources, the carbon content of the electricity powering EVs will continuously decrease. This aligns with the climate goals set in the recent United Nations climate change conference in Paris [43] and the European Union (EU) 2030 climate and energy framework.

The future of electromobility is strongly linked to the degree of penetration of renewable energy sources (RES) in the future power systems. Thus, if the energy sources mix, which is used to produce the electricity that will supply the EVs, has low (or even zero) GHG emissions, moving from conventional to electric vehicles will also lead to GHG emissions reduction. Presently, the power portfolio of the majority of the countries is dominated by fossil fuel-based power stations (e.g., lignite, hard coal, oil, natural gas) hindering the shifting to EVs. The real benefits as far as GHG emissions are concerned depend on the clean electricity generation [44]. A 2013 study on the Chinese power system revealed that shifting from conventional to electric cars in China would actually increase carbon emissions, as the current Chinese power system is heavily dependent on carbon-intense coal power plants [45]. With the growing share of RES in countries' power systems, the benefits of the electrification of the road transport will be better exploited.

Parallel to the transformation of the central power system, the widespread use of EVs will create new opportunities for the electricity distribution both in regional- and city-level. So far EVs are charged from grid-to-vehicle (G2V) connections. The ultimate target is to design systems where a bi-directional connection will be developed, a concept known as vehicle-to-grid (V2G) schemes [46]. V2G interaction will transform the EVs' fleet to a large and flexible energy storage capacity, providing invaluable flexibility to the power system, and allowing the efficient operation of conventional power plants (i.e., thermal). V2G schemes would increase the capacity factors of base and mid-load power plants. The latter will allow further reduction of GHG emissions, supporting the fulfilment of climate targets. Moreover, it will allow higher shares of variable/intermittent energy sources (e.g., solar, wind) in the future energy systems. At present, technological knowledge to equip EVs in a way that can also provide V2G services does exist. However, the relevant technology has not yet reached a degree of maturity that justifies the required additional cost [47]. More importantly, the operational framework of V2G services has not been defined and the policy regulations are still to be placed.

Considering the impact of the dual relationship between vehicles and the energy system, it is expected that an unprecedented change will take place in the way vehicles are used in urban environments. Alteration in the vehicle ownership schemes, novel usage paradigms and new infrastructure that accommodates the special features of the EV technology will certainly change the future cities.

4. Bus Rapid Transit

Bus rapid transit (BRT) is a hybrid form of urban passenger transportation, bringing together bus' flexibility and cost-effectiveness with rail-like standards of service provision and rights-of-way. According to [48] BRT has been thus far successful due to evidence of an ability to implement mass transportation capacity quickly and at a low to moderate cost especially when compared with metro and light rail investments. BRT essentially rebrands, the humblest of all public transport modes, transforming conventional bus systems into a new mode that is given the license to dominate the host city's landscape, by taking space from cars, serving according to [49] more than 32 million passengers per day in 164 cities across the globe. Despite these numbers and its competitive advantages BRT has not been yet embraced universally to the degree that other mass-transit systems have; there is still a massive untapped potential that needs to be realised if the future of transportation is to be developed in a balanced way that embraces public transport initiatives.

4.1. The Elements Differentiating Bus Rapid Transit

A fully operational BRT system, which is superior in every facet of its activities from a conventional bus system, and thus should not to be misinterpreted as one, according to [50] consists of the following elements:

1. State-of-the-art vehicles, including in some cases massive bi-articulated buses, which characterise BRT's image and identity, but also play according to [51] a strong role in achieving measurable performance success.
2. Stops, stations, terminals and corridors approximating the standards of rail-like infrastructure.
3. A variety of rights-of-way including dedicated lanes on mixed traffic streets, special BRT busways completely segregated from road traffic and bus priority in signalised intersections. BRT routes can run nearly anywhere including abandoned rail lines, highway medians and city streets [52].
4. Pre-board fare collection, for speeding up services and providing a robust funding mechanism for the system's long-term fiscal viability.
5. The use of Information and Communication Technologies (ICT), for enhancing customer convenience, speed, reliability, integration, and safety.
6. Frequent all-day services that need to operate at least for 16 hours per day with peak headways of 10 min or less [53].
7. Brand identity, entailing of perceptual constructs substantiated by the strategic deployment, placement, and management of communication elements that allow people to distinguish the superior qualities of a BRT system. These include visual and nominal identifiers (e.g., system name and logo), a color palette and long-term strategic marketing and advertising plans [54].

4.2. Origins and Worldwide Applications

The most important point of reference for BRT systems is South America, which is the birthplace of this mass-transit concept and generates, as of November 2017, 60.74% of the travel demand worldwide for these services. The first real BRT system was implemented in Curitiba, Brazil, in 1963, although dedicated bus lanes were not operating until 1974 [55]. It was based in the idea of its mayor and architect Mr. Jaime Lerner, who wanted to re-invent the public transport system of Curitiba but had no funds to build a metro or a light rail system. Curitiba's BRT until this very day remains one of the leading and most innovative schemes running in seven corridors spanning across 74 km and being responsible for 566,500 passenger trips per day [49]. Other BRT systems that have achieved so far to at least dominate their respective city's modal split are Bogotá's TransMilenio

BRT (Colombia), widely considered to be the most successful scheme in the world in terms of performance, innovation, capacity to create modal shift and ability to attract additional funding resources, Istanbul's Metrobüs (Turkey) the only intercontinental scheme in the world, bridging Europe with Asia with its 52 km long corridor, and the only European scheme comparable to size with the Latin American systems, the Guangzhou BRT (China), Asia's second busiest system after the Taipei BRT, that handles approximately 850,000 passenger trips daily with a peak passenger flow second only to the TransMilenio and the still developing New York's BRT, North America's largest scheme with 13 bus service routes serving currently 245,000 passengers in a day-to-day basis [49].

4.3. Problems and Challenges

The key challenges associated with BRT applications thus far, which have marginalised success for some schemes, refer among others to:

1. Rushed implementation; transitioning to BRT needs time and careful planning including incremental implementation.
2. Tight financial planning (i.e., absence of operational subsidies).
3. Extremely high vehicle occupancy levels that in some cases reach six to seven standees per m^2 which adversely impact user experience.
4. Infrastructure maintenance issues; state-of-the-art bus infrastructure is more expensive and more difficult to sustain.
5. Inability to absorb extra travel demand due to a saturated system that lacks the capacity to expand further.
6. Difficulties with implementing and regulating fare collection.
7. Inefficient communication especially during disruptions caused by road works.
8. Lack of integration with feeder modes like walking or cycling.
9. The belief shared by many policymakers that BRT, despite its merits, is still a second-tier solution when compared to metro or light rail schemes.
10. Failure to brand and operate BRT as a significant upgrade from conventional buses (i.e., not providing essential infrastructure and rights-of-priority, equivalent to a BRT standard is a recipe for failure).

4.4. Solutions for a BRT-Infused Future

There are many ways to surpass these challenges. First the planning process chosen needs to mirror the specific needs and characteristics of the city hosting the scheme; low quality copycats or rushed mediocre solutions mascaraed as BRT would not work. Buses need to be given the green light to take over the city; they should be clearly prioritised over cars in any facet of urban planning and be well-integrated with complementary travel modes. A strong political consensus (or at least a political protagonist like Mr. Jaime Lerner) is often a pre-requisite for success. Financial support and subsidies could be needed. Branding, image-making, marketing, advertising and communication tools together with the provision of road user education and a feedback system enabling dynamic interaction between the system operators and the users are all of critical importance. BRT should be portrayed as an exciting and tangible long-term mobility solution and an opportunity for sustainable growth and not as a mere upgrade of an uninspiring fleet of conventional buses.

Adopting a scheme that, in principle, combines the convenience, reliability and finesse of a tram or metro system with the flexibility, maneuverability, adaptability and ease to operate of a conventional bus system could be of paramount importance for any city that has aspirations of becoming smarter. BRT is a realistic proposition that can be incrementally implemented in a variety of settings and types with significantly smaller investment costs than other mass-transit systems. Research on existing international practice [50,56] strongly recommends that BRT can be a publicly acceptable mobility mechanism for reducing traffic-induced externalities and enhancing livability for cities.

5. Hyperloop

Tube-based transportation, after years of being considered an unrealistic proposition with fundamental flaws and weaknesses that was outrageously expensive and risk-prone to develop and run, has recently re-emerged in a dynamic fashion under the Hyperloop brand with the vision to re-invent ground public transport offering services travelling at faster speeds than commercial flights in prices comparable to these of conventional rail services. Hyperloop widely associated with Tesla's and SpaceX's architect and founder Mr. Elon Musk, since many people consider the latest take in tube-based transport to be his brain-child, has been around as a concept for many decades. The first vacuum tube train system using a magnetic levitation (maglev) line and tubes or tunnels was conceived by Russian professor Boris Weinberg in the early 1900s but did not progress beyond the stage of early modelling. The concept has seen many different names and variations: Airless Electric Way, Vactrain, Vaculev, Evacuated Tube Technology [57] but now Hyperloop is the most universally acknowledged term in use and the one adopted by the present article.

5.1. Hyperloop Definition

Hyperloop will be based on the use of pods that will typically carry 12–24 people at 10 s intervals, levitating on air or magnetic cushions in low-pressure tubes. A combination of linear induction motors and lack of air drag will in theory enable these pods to reach speeds close to that of sound [58]. The expectation is that Hyperloop will be able to travel at speeds allowing this mode to be faster than any passenger aircraft; traveling times between London to Edinburgh and Los Angeles to San Francisco, two of the most discussed origin-destination combinations will be just 45 and 30 min respectively.

5.2. Opportunities and Challenges

Hyperloop pods could be offering many more advantages to travelers and societies besides their speed; they will provide reliability comparable to that of a high-speed train, create substantially less environmental damage than other modes, reduce road traffic and air traffic congestion, decrease traffic accidents, create millions of new jobs, minimise energy consumption since they will be fuelled by electricity and be unaffected by weather conditions. Nevertheless there is a strong consensus, at least when reviewing the initial design plans offered in Mr. Elon Musk's 57-page open-source Hyperloop manifesto [59], that the cost of infrastructure and maintenance, vulnerability to seismic activity, susceptibility to accidents and terrorism and the difficulty of operating when equipment malfunctions happen or emergency evacuations are in need, are severely underestimated. Other critics of Hyperloop focus on the user experience per se. Riding in a narrow and windowless capsule-like pod inside a sealed steel tunnel, that is subjected to significant acceleration forces and having to tolerate high noise levels due to air being compressed and ducted around the capsule at near-sonic speeds and absorbing vibrations and jostling can be an unpleasant and even frightful experience [60]. Even if the tube journey is relatively smooth, at high speeds, the smallest deviations from a straight path may add substantial cause for discomfort.

5.3. Current Development and Future Promise

As of November 2017 there are eight companies that have dedicated efforts to develop and commercialise Hyperloop technologies. These are in chronological order from the moment they launch their plans, Virgin Hyperloop One, Hyperloop Transportation Technologies, TransPod, DGWHyperloop, Arrivo, Hardt Global Mobility, Hyper Chariot and the Boring Company/SpaceX. Hyperloop One, lately supported by Sir Richard Branson's Virgin that has invested an undisclosed amount of funds after the second successful testing demonstration, is the frontrunner to realise this vision. Nonetheless, all of the listed companies have a clear vision about Hypeloop's future. Mr. Musk's brand, for instance, was the one that initiated this discussion and the latest to announce the decision to heavily invest on long distance routes in straight lines, such as New York to Washington DC, after years of simply nurturing and facilitating progress in the field without actively being involved in a commercial sense. Their plan is to use pressurised pods in a depressurised tunnel to allow speeds up to approximately 600 mph; as of now SpaceX is building a Hyperloop system at its headquarters in Hawthorne, California, approximately one mile in length with a six foot outer diameter.

Hyperloop is projected to have a relatively strong performance on social and environmental performance criteria and can potentially be a very safe mode but at the same time might end up being more expensive than what its investors aspire to be since the low capacity, due to the small vehicles, may lead to high break-even fares that might be more applicable for the premium passenger transport market [61]. Hyperloop is still a very novel and untested concept that can develop in many different ways. It is projected to be a very powerful and potentially disruptive technology that will revolutionise transport futures with an impact that could be even more profound than that of CAVs, especially if it ends up replacing high-speed rail services.

6. Shared Use Mobility

Shared use mobility (SUM) is transforming the way people move around cities and is challenging consolidated transport modes such as the private car, taxi and public transport [62]. SUM schemes are in principle an entirely different breed of travel alternatives that try to maximise the utilisation levels of the finite mobility resources that a society can realistically afford to have by disengaging their usage from ownership-bound limitations. SUM schemes provide fleets of vehicles that can be accessed and ridden by their subscribers (subscriptions are open to the general public) on an as-needed basis typically for a modest fee directly associated with usage criteria.

According to [63] the various modes that could be classified under the umbrella term SUM are car-sharing, ride-sharing, bike-sharing, ride-sourcing (or ride-hailing), personal vehicle-sharing (i.e., P2P car-sharing and fractional ownership) and scooter-sharing. Lately SUM initiatives are also used in the freight and logistics industry since these principles boost profitability; maximising the load of HGVs and eventually cutting down excessive trips is cost-effective.

In general all SUM services:

1. Provide a wider range of mobility choices.
2. Deliver first- and last-mile solutions to help riders connect with other forms of transport.
3. Reduce traffic congestion, vehicle km travelled and CO_2 emissions.
4. Lessen parking pressures and free up land for new uses.
5. Create independence for those who cannot afford buying or running their own private vehicle.
6. Increase efficiency, flexibility and convenience.
7. Cut down transportation costs for individuals and households.
8. Help drivers to share trip costs or earn extra income by utilising excess vehicle capacity.
9. Establish an ethos of sharing resources on as-needed basis within communities.

6.1. Bike-Sharing

Bike-sharing systems, also described as public bicycles or cycle hire programmes, lately enjoy an unprecedented rise with close to 1500 schemes of various types and scales operating worldwide [64] as of November 2017. Bike-sharing can be defined as a locally customised provision of affordable short-term access to bicycles on an as-needed basis that could extend the reach of public transit services to final destinations and be a door-opener for increased bicycle usage [65]. Bike-sharing was first launched in Europe back in 1965 but re-emerged about a decade ago as a result of enhancements of ICT capabilitiesthat allowed a lot more control and safeguards in renting out bicycles. Some of the most popular schemes today facilitating thousands of trips per day are Barcelona's Bicing (Spain), London's Santander Cycles (UK), Paris Vélib' (France), Hangzhou Public Bicycle (China), BiXi Montreal (Canada) and New York's Citi Bike (USA).

The key advantages of bike-sharing are decreases in traffic congestion and fuel consumption, reductions of greenhouse gas emissions, flexible mobility, physical activity benefits, individual financial savings and support for multimodal transport connections [66]. Nonetheless, there are critical problems that bike-sharing is currently facing that refer to: schemes being systematically underused, misused or severely underdeveloped; political or/and public resistance when there is a need to sacrifice car parking space; slow and complex planning procedures; no appetite for incremental expansion to more destinations; cycling legislation restrictions forcing compulsory helmet use and thus creating the need for people to own and carry or alternatively rent a helmet; unprotected bike-sharing infrastructure; cycling safety concerns; severe competition between similar schemes; unrealistic operator expectations in terms of return on investment; lack of adequate cycling investment by the host city that could complement and support bike-sharing; and not being appropriate for hilly and cold weather environments. Another problem that the conventional station-oriented schemes face (i.e., the inability to provide door-to-door services) seems to be solved by the introduction of the dockless schemes that started in China, from companies like Ofo and Mobike, and now provide smart bicycles that lock and unlock through the use of mobile applications in hundreds of cities. There are some issues with these new-age systems especially when these do not have GPS-based technology, their own mobile application to track, lock and unlock the bicycles, good safeguards, effective communication/branding tools and follow over-aggressive and rushed expansion strategies. Nevertheless, learning from the mistakes of the past and taking advantage of the continuously growing potential of IoT will allow for enhanced bike-sharing services in the future.

6.2. Car-Sharing

Car-sharing is another mode that has emerged to challenge the hegemony of private car use in many cities [67] being a service that is appealing to road users who make only occasional use of an automobile and to those who want sporadic access to a car of a different type than the one they might be typically using. Car-sharing (also known as car clubs) is an evolving mobility industry in which subscribed drivers can access for a moderate cost a fleet of shared vehicles for short-term use only. Since the beginning of organised car-sharing activities, it has been solidified that car-sharing can encourage more sustainable travel behaviour, reduce the need of owning private vehicles, and promote dense urban forms [68]. Car-sharing can be perhaps thought off as a systematic short-term car-rental initiative [69] but is actually significantly different from traditional car rentals in many ways: car-sharing is not restricted by office hours and can easily run 24/7 because reservation, pickup, and return are all self-service and app-based; automobiles are rented usually for significantly shorter time periods typically spanning for a few hours; users are registered subscribers of the scheme and therefore known qualities that have passed the necessary control checks; fuel costs usually included in the rates; there are more pick-up and drop-off points that tend to be closer to mobility hubs (i.e., thus more potential for integration with other modes); better insurance policies are in place; car-sharing is usually more inexpensive than car rentals.

Zipcar (USA/worldwide), Cowheels Car Club (UK), Enjoy (Italy), GoGet (Australia), Greenwheels (Germany), Cambio (Germany) are all relatively successful schemes. Several car rental companies launched their own car-sharing services including Avis on Location by Avis and Hertz on Demand by Hertz, while EasyCar Club is an Easyjet subsidiary. Many schemes nowadays are electromobile or at least have a number of electric automobiles in their fleet; coupling SUM with electromobility initiatives amplifies the ability of any given scheme to promote urban sustainable growth and better energy consumption behaviours. Autolib' is an electric car-sharing service, which was launched in Paris (France), in late 2011, operated by the Bolloré industrial group. The Autolib' scheme maintains a fleet of 4000 all-electric Bluecars for public use on a paid subscription basis, employing a citywide network of parking and charging stations.

6.3. Ride-Sharing

Ride-sharing (or carpooling) refers to a mode of transportation in which individual travellers share a vehicle for a trip and split travel costs such as gas, toll, and parking fees with others that have similar itineraries and time schedules [70]. This sharing approach has an immediate and potentially easily measurable impact on mobility patterns since if three potential drivers, people that are not susceptible to shift to another mode of transportation, decide to share a ride this means that only one car will be used instead of three. In theory, ride-sharing is a system which combines the flexibility and speed of private cars with the reduced cost of fixed-line systems and is directly battling the negative externalities of single occupant car travel, which is the most unsustainable form of travel behaviour. Ride-sharing is relevant, and if presented in a potent way could be also particularly attractive, for commuters that want to go to work in a cost-effective and flexible way; there are many employers that promote and organise ride-sharing programmes for their staff. Advantages of ride-sharing for participants (both drivers and passengers), to society, and to the environment include saving travel costs, reducing travel time, mitigating traffic congestion, conserving fuel, and reducing air pollution [71,72].

Today, dedicated platforms allow drivers to post their rides online helping to mitigate many issues, which previously limited ride-sharing. These digital platforms help by establishing trust among strangers through rating and review systems, meaningful profiles, user verification, and automated booking and payment processes and by dramatically decreasing transactional cost for ride listing and search [73]. These technological advancements, which will only continue to improve as IoT evolves and real-time monitoring and live matching capabilities become better, have already enabled the establishment of large ride-sharing initiatives like RelayRides, BlaBlaCar, or Carpooling.com that facilitate millions of trips per day.

6.4. Ride-Sourcing

Ride-sourcing refers to an emerging transport service that allows registered private car owners to drive their own vehicles to provide for-hire rides. More specifically, ride-sourcing dynamically matches travel supply and demand by enabling travellers to request car rides in real-time from potential suppliers using a smartphone application [74]. Ride-splitting is an interesting form of ride-sourcing where riders with similar origins and destinations are matched to the same ride-sourcing driver and vehicle in real-time, and the ride and costs are split among users [63,75]. Ride-sourcing, in any of its variations, is distinct from ride-sharing since ride-sourcing drivers operate for-profit per se and provide rides not subsidiary to their own trips; this is utterly a new-age taxi-like service that came to life with the recent emergence of app-based platforms. Because of their convenience and competitive prices, ride-sourcing services provided by companies like Uber and Lyft, typically classified under the umbrella term Transportation Network Companies (TNS), have successfully attracted many riders, eroding the traditional taxi market and creating controversy [76].

Ride-sourcing companies, despite their success, have troubled policymakers and legislators; there is no consensus of how to embrace and regulate these measures. While many cities have not yet given their verdict about TNS services, some, with London being the latest and possibly the largest city to do so, have decided to ban them considering these services as illegal on the premise that constitute unfair competition for their regulated taxi services and create public safety and security implications. There are other cities that have adopted them and support them as a new thriving travel mode that gives to their residents more mobility choices and have passed ride-sourcing laws and regulations that help them prosper. Although these legislative frameworks have some differences, they all essentially codify the insurance coverage, driver background check, and inspection protocols that ride-sourcing companies already have in place [76]. The digital labour of Uber-like businesses is also a puzzling issue [77]; drivers working for TNS are neither real contractors nor employees, typically receive smaller incomes than their load of work implies, are bound to follow TNS rules and orders of how and when to operate (i.e., flexibility of choosing when to operate might be penalised) and are assessed at a per-trip basis.

If these issues are addressed, the authors, believe that ride-sourcing services could be of some value for crafting more livable futures. Their impact however may not be as significant or positive as those of other SUM initiatives since TNS companies work for profit (diminishing the sharing factor's value) and could be attracting people currently using public transport services, which is not an ideal modal shift direction.

7. Mobility-As-A-Service

The future of urban mobility, may not be about creating and adapting to new, transformative and disruptive modes of transportation or vehicles but in innovating the ways the current transport is used. SUM could be viewed as a door-opener for a more radical solution known as mobility-as-a-service (MaaS) that replaces privately owned transport with personalised mobility packages that give access to multiple travel modes on an as-needed basis by exploiting the riches of modern information and communication technologies. MaaS is the holistic provision of integrated on-demand multimodal services enabled and accessed via powerful digital platforms that eliminates the need for multiple tickets and payments for subscribers, helps users to optimise their transport choices, provides access to real-time journey information, including traffic and even weather conditions and allows commuters to surpass issues, unexpectedly arising during their journey. It is a way of making urban travel controlled, resilient, and convenient. The transport industry is closer than ever before to making this future a reality. Various changes to the structure and management of public transport services like smart ticketing [78] and the lately booming SUM initiatives are clearly aiming at integrating mobility services and hinting to this direction [79,80].

The present digitalisation trend is the main driver enabling this shift [81]. Simultaneous availability of wireless connection, 3G/4G/5G networks and interfaces, such as smartphones and tablets, enable access to shared mobility services at any place and time convenient to consumers. Accessible internet connections allow not only the effective utilisation of shared transport modes but also the utilisation of other services that make urban commuting easier. Such services include navigation, which helps monitor and control the journey, journey information and planning, which allows comparing various travel options and mode combinations by, for example, the cost of the journey or the time it takes, and cashless payments for transportation. Although already widely utilised, such services are unimodal in their nature, and the benefits of using them are moderated by the need of flicking between the screens when creating a journey. A seamless unification is thus the key for MaaS.

7.1. Current Practice

Although MaaS is at a very early stage in its development, there is already some experimentation underway [79,80,82–84]. One of the most famous MaaS initiatives is the Whim mobile application. Since 2016, the residents of the Finnish capital Helsinki have been able to plan their journeys using Whim by entering a destination, selecting their preferred transport mode or a combination of the modes where no single mode could cover the journey, and pay for the service as part of their monthly subscription or in a pay-as-you-go basis. The mobile application puts together more than 2500 taxis, rental cars and public transport as well as provides information on all the routes, fees and timetables [83,85,86]. Another well-known MaaS initiative is the Qixxit electronic application of Deutsche Bahn. Whilst Whim services cover Helsinki's area solely, the Qixxit application offers mobility services all over Germany. The services include taxi, public transportation and access to SUM schemes; however, although the cashless payment service is available, a separate ticket needs to be purchased for each of the vehicle types of the multimodal journey [87]. Other examples of MaaS initiatives that have been piloted or are functional at the moment include the Viennese SMILE application and Daimler's Moovel, which is operational all over Germany as well as in Helsinki [82].

7.2. Potential Benefits

Many researchers believe in the potential of MaaS to bring significant social, economic and environmental paybacks to cities and urban societies. The social benefits of MaaS may include the access to opportunities, such as healthcare and leisure, improved social inclusion and reduced isolation as well as the support of healthier and more active lifestyles. The economic benefits could refer to enhanced access to jobs and skills as well as services and markets, and, in addition, making the urban areas more attractive to live, work and invest in. And, finally, the environmental benefits are projected to be the ones that deal with the main urban mobility challenges, namely traffic congestion and the consequent air and noise pollution, since MaaS is encouraging more sustainable transport choices [79,82,88,89]. Nonetheless, the potential benefits of MaaS have not been tested systematically yet in real-life terms; they are mostly theoretical. As MaaS is a new mobility service and its implementation is limited, there is a scarcity of research that managed to identify the impact of MaaS on travel behaviour, while at the same time data availability is limited deterring the development of models to assess its effect on travel demand [90].

So far the only example of a MaaS initiative that has been thoroughly examined for its potential to improve urban mobility is the UbiGo project described in studies [84,91,92]. UbiGo is the MaaS web interface that offered access to a range of travel services to its 195 customers all being residents of the city of Gothenburg, Sweden. Customers paid a monthly subscription of minimum 1200 SEK, equivalent to €135 at the time, which included personalised combination of, and a number of credits for, a range of different transportation options, such as bus, tram, taxi, car- and bike-sharing. The application allowed its users to book and activate tickets and trips, amend bookings and access already activated tickets. Customer service and support was also provided within the UbiGo application. The pilot project was operational between 1 November 2013 and 30 April 2014. During this time span, the UbiGo customers were regularly interviewed, and the collected interview data was utilised to analyse the effect the use of UbiGo had on customers' attitude towards car ownership and the possible impact of the implementation of UbiGo on traffic congestion and the environment. At the end of the trial, the majority of UbiGo users reported that they would want to continue their subscriptions and became more positive towards SUM options as well as public transport and less positive towards private cars. As a result, the overall number of journeys, performed by private cars, reduced, which, patently, could improve the traffic situation in the city [84,91,92].

7.3. Barriers and Challenges that Need to Addressed

The first MaaS transport systems are already operating and their benefits seem, according to early-stage research at least, to be real but it is difficult for the urban transport sector to make the leap as yet and provide urban residents with this breed of seamless digitally-planned travel. There are still considerable barriers that challenge, and for now do not allow, the unification of transport infrastructure and transport related technologies [81,93]. Firstly, the public transport and SUM providers as well the providers of digital interfaces and electronic applications are currently lacking the desire to cooperate with each other and share the available data, which can be easily explained by the service providers facing the risk of losing the direct relationship with their customers. Secondly, the legislation in many countries does not act as a supporter of innovation and change when it comes to mobility. For instance, the current taxation policies create barriers for behavioural change, allowing urban commuters to continue travelling by private cars. Thirdly, national and local governments are not actively giving, thus far, an emphasis on financially supporting MaaS pioneers. This lack of support was the main reason behind the discontinuation of the Swedish UbiGo pilot.

7.4. The Future of Mobility-As-A-Service

Although MaaS is a fairly new transport paradigm, it has great potential and could soon evolve beyond pilot applications. The likely benefits that MaaS could deliver to the urban environment, by reducing road traffic congestion in the cities, are overwhelming. The benefits for urban travelers are just as compelling; a public that has already got experience with similar mechanisms, such as travel aggregators that allow booking any preferred flight options with add-on services matching them with hotels and car rentals, will be given an opportunity to get in a similar fashion, travel benefits on a daily basis. MaaS will revolutionise people's ability to reach destinations without the need of a car. Cities need to push towards this direction by investing more on research and development and by trying to start up their own piloting MaaS programmes.

8. Discussion and Conclusions

With the transformative powers of urbanisation reaching unprecedented heights and redefining the dynamics and direction of urban development across the globe, cities face more than ever before the need to craft more sustainable and smart pathways in their attempt to provide enhanced standards of livability. Transport is at the very heart of this developmental process being the apparatus that is set to provide people with seamless connectivity and access to destinations and activities that are necessary for them; as [94] suggested the rise of the modern city is built on mobility. Improving access opportunities, decreasing traffic congestion, preventing environmental degradation, enhancing traffic safety and security, ensuring integration and multimodality, maximising the return from the offerings of mobility and wireless technologies and reshaping conventional transport wisdom that is still dominated by fossil-fueled, human-led, private car considerations are challenges that need to be addressed effectively so that transport plays its definitive role.

The mobility initiatives that have been highlighted by the present work can be protagonists in helping transport to transform and set a solid foundation for sustainable growth. Transport will not change and evolve towards a single direction. A balanced mix between high-tech and low-tech solutions must be provided; especially since there is a need to cater for the transition period between today's mobility paradigm and an AI-led one. On the one hand, there will be disruptive technologies altering how societies envision and manage mobility and reshaping how transport networks will operate, technologies like CAVs and Hyperloop, and on the other hand there will be less intimidating initiatives that will help people get the most out of the untapped potential of more traditional modes, initiatives like BRT and SUM.

The process of transforming the transport system, however, will not be uncomplicated, predictable, unproblematic or without risks and early-stage fiascos. State-of-the-art concepts with disrupting nature like CAVs and Hyperloop or others, like MaaS that may not alter the transport network per se but nevertheless mean to redefine travel behaviour by exploiting the riches of information technologies and integration capabilities, are not easy to implement and not always likely to be acceptable from societies without a fair amount of criticism, reluctance, suspicion and negativity. The transition will need time, patience, flexibility, political persistence and continuous investment. Many trials will go wrong before scientists, technology developers, mobility providers and policymakers get it right; there is a need for a 'trial and error' process. Efforts should be directed not only towards technology, infrastructure and service provision per se, but towards supporting instruments like legislation, education, marketing and branding that will allow for these changes to be viable long-term. Potential distributional impacts should be also closely monitored and controlled so that the likely benefits of these mobility initiatives are not enjoyed only by high-end users; these should be mechanisms designed for all and not instruments that will create new layers of transport-related social exclusion. Future transportation should be designed to work in the context of developing countries too; progress should not be an excuse for creating a two- or three-speed world but one for bridging knowledge gaps. To the extent that this would be financially feasible, the potential for extending some of these services (or linking them at least) with more rural contexts should be also investigated.

There will also be a need for measures, not in the scope of this paper but still of vital importance, which instead of trying to create voluntary travel behaviour change, as the ones outlined herein, they will try to enforce and regulate modal shift pushing people out of their cars. Policies like road pricing as defined by [95–97] and other travel demand measures involving charging, taxation and bans have a key role to play. This need for 'sticks' further highlights the underlying tensions that will continue to exist in the future between a car-centric school of thought that will be likely to invest in and prioritise continued automobility and those realising that changing the vehicle's engine or removing the driver does not address fully the real issue which is ultimately about achieving a more balanced modal share; this is a transition that should be primarily centred around the provision of better public transport and active mobility options.

All in all, there is a need for policymakers to integrate the mobility mechanisms this paper reviewed or at the very least create synergies between their respective technologies; potential benefits will be amplified if this is the case. A near perfect version of transport futures, based on such an integrated approach therefore, would be revolved around shared used CAVs fuelled by electricity, produced solely from renewable energy sources, that will operate under MaaS principles, meaning that they should be accessible only as part of packages primarily offering electrified public transport from initiatives like BRT and Hyperloop.

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Abbreviations

ACV	Autonomous and connected vehicle
ADAS	Advanced driver assistance systems
AI	Artificial intelligence
AV	Autonomous vehicle
BEV	Battery electric vehicle
BRT	Bus rapid transit
CAV	Connected and autonomous vehicle
EV	Electric vehicle
GHG	Greenhouse gas
G2V	Grid-to-vehicle
HGV	Heavy goods vehicle
ICT	Information and communication technologies
IoT	Internet of things
MaaS	Mobility-as-a-service
NEV	Neighbourhood electric vehicle
PHEV	Plug-in hybrid electric vehicle
RES	Renewable energy sources
SUM	Shared use mobility
TNS	Transportation network companies
V2G	Vehicle-to-grid

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