Will the ‘smart mobility’ revolution matter?

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‘Smart Mobility’: the transport sector in transition?

In essence, ‘smart mobility’ is the belief that by significantly increasing the application of computer science technologies in the transport sector, long-term aspirations for more efficient movement of people and goods, with fewer negative consequences, will finally be realised. In this vein, since 2010, there has been a steady stream of publications from global consultancy firms seeking at once to offer an ‘insider’s guide’ to a revolution in the transport sector identified as highly-lucrative, whilst showcasing the credentials of key personnel to provide services in that transforming market (e.g. Lerner 2011, Graham 2013, Van Audenhove *et al*. 2014, Bouton *et al*. 2015). To this end, Arthur D Little (Lerner 2011) identified ‘niches of potential’ related to 39 ‘key technologies’ and 36 ‘potential urban mobility business models’ which would, by 2050, be contributing to a market forecast to be worth $829 billion per annum. The same firm, in a follow-up publication three years later (Van Audenhove *et al*. 2014: 7), referred to “a clear trend” to “Urban Mobility 2.0,” identifying “[i]mperatives to shape extended mobility ecosystems of tomorrow.” The following year, McKinsey & Co (Bouton, *et al*. 2015) titled its offering “urban mobility at a tipping point”.

These visions of the future show a high degree of conformity around a global perspective in which the industrialising states are assumed to undergo significant urbanisation and economic growth. Further, they share beliefs in a trend away from traditional transport systems to ‘mobility services’, the latter increasingly combining transport and digital technologies to deliver more personalised and flexible travel options. This integrative platform serves within these visions to underlie a novel mobility ‘ecosystem’, which is foreseen to nurture two technical transitions: i) the shift from internal combustion engines powered by liquid carbon fuels to battery-electric vehicles, and ii) the adoption of road vehicles which are increasingly driven by robotic systems and digitally connected with other road system 'agents' in a cooperative way. Moreover, within this new ecosystem, levels of sharing of road vehicles not seen in the industrialised states since prior to mass adoption of the private car are predicted to emerge. Taken together, the facets of this new 'smart' mobility are presented as offering cleaner, more efficient, and greater volumes of mobility, whilst creating significant economic rewards in the process.

Indeed, from transport sector professionals committed to sustainable development and government departments, there is enthusiasm that smart mobility will be a different basis of mobility precisely because it will break the historic association between transport development and both energy consumption and social and environmental costs (Department for Transport (DfT) 2015). Here, rather than underpinning the next wave of capitalism or furthering 'progress', smart mobility is able to underpin more 'liveable', productive cities, in which accessibility needs are met but with urban spaces less dominated by the infrastructure and practices associated with the private car (Skinner and Bidwell 2016). Central to this vision is the idea of the 'better mobility mix' in which informed, rational and pro-social citizens choose the form of travel that is 'optimised' for the situation. In short, the shared 'policy discourse' (Hajer 1995) asserts that the future transport systems in the industrialised democracies should exhibit:

- fewer vehicles on the road networks than now
- significantly higher average vehicle loading
- simplified access to information, ticketing and the services themselves, regardless of transport mode or which agency is the supplier
- vehicles that are powered in a more energy efficient way and which produce fewer in-street emissions, and
- effective 'cohabitation' between motor vehicles other road uses on all but limited-access highways.

With the important exception of 'higher vehicle occupancy', which immediately conflicts with important social norms around personal space and individual agency, and also some difference of views around the sharing of streets, the ‘future of urban mobility’ would be for many, and in many respects, a positive one. Yet a number of important strategic questions must be answered before it can be ascertained whether, and how, this smart mobility revolution ‘matters’. These include: Is such a vision underpinned by feasible technological change? Under what circumstances? If it is feasible, by when might it be realised? How widespread and socially inclusive might its influence be: will it be the mainstream mobility experience of most citizens, or confined to a handful of ‘world cities’? And most importantly, would the sociotechnical changes proposed actually result in the economic and environmental benefits promised?

In seeking to address such questions, we will in this chapter summarise and interrogate the four key technological shifts that underpin the transition to a new mobility, considering in turn connected autonomous vehicles (CAVs), electric vehicles (EVs), digitally-enabled mobility (DEM) and collaborative / shared mobility (CM). We consider the factors that support and constrain the development of these four trends and consider how far each is likely to support or threaten current policy objectives. CAVs are considered in the next section, then EVs in the following section. The emergence of digitally-enabled and collaborative mobilities are sufficiently intertwined that we consider them in an integrated third section. Our emphasis is on urban areas, as much of the development and policy focus is currently there, although we draw out implications for suburban and rural areas where possible (Chapter 12). In the final section, we seek to synthesise the smart mobility developments, considering in more detail their interactions and dependences, in order to reach a conclusion about whether the four developments together suggest that more sustainable mobility is now in reach.

Connected autonomous vehicles

The emergence of CAVs involves a range of technologies. These are divisible into sensing, processing and decision-making systems that provide automated driving or ‘self’ driving capacity to road vehicles, and communications systems which enable connectivity between vehicles or between vehicles and a road infrastructure management system. Autonomous vehicles do not need to be connected to function, but a number of technical advantages, including data acquisition and processing efficiency, have led commentators to argue they will be (KPMG/CAR 2012). One of the key benefits would be the possibility to manage and optimise the movements of individual vehicles and flow of traffic streams, at which point it is in fact more appropriate to refer to 'automated' rather than 'autonomous' vehicles. From the perspective of the individual citizen-motorist, the road system becomes a very different proposition, with 'free will' potentially limited to selecting origin and destination, and perhaps some routing and timing preferences. It also greatly increases potential concerns about cybersecurity, if a whole system, rather than an individual vehicle, might potentially be 'hacked'.

Apparently accepting the view that cybersecurity measures will be effective, the UK government (DfT 2015) has identified a broad range of potential benefits from the adoption of CAVs, including the possibility to enhance the mobility of groups unable to drive themselves, energy-use and emissions reductions, as well as 'freeing up' time spent driving for a more productive journey experience. The most political salient argument to date, however, has been the potential to approach 'vision zero' levels of road safety by eliminating human errors from the driving task, identified as present in over 90% of incidents (Fagnant and Kockelman 2015). (And whilst we focus here on autonomy in the road passenger transport sector, as a critical subsector for transport policy, automation is already important on railways, in aviation and in the logistics supply chain in the form of automated warehouses. It has potential in container terminals, shipping movements within ports and eventually on the open seas, and as a means of 'last mile' delivery by aerial drone (Paddeu *et al*. 2019). Moreover, automation is well established in transport-sector support systems, from self-service ticket machines through to unstaffed public cycle hire.)

Growing automation is a cross-sectoral technological change that is affecting domains ranging from hazardous industrial activities and precision tasks such as surgery and healthcare, to labour intensive activities such as driving. An analysis published in 2017 (IPPR 2017: 3) estimated that "60 per cent of occupations have at least 30 per cent of activities which could be automated with already-proven technologies," though with considerable variation between sectors and roles. Ultimately, if all the technical, regulatory, financial, and public acceptance barriers are overcome, professional road transport-driving jobs could disappear. At the same time, a far greater quantity of labour is invested by drivers transporting themselves or others on a personal or voluntary basis or for employer's business during the hours of work. Automated vehicles could eliminate the need for a driver to provide 'escort' trips to deliver others, and it may be possible to put in-vehicle time to a more productive (or 'consumptive') use. It is for this reason that, of the new technologies, automation has the potential to radically influence not just the transport system, but the whole basis of the automobile society.

It is necessary to point out that even just considering technical constraints, the transition to fully automated road vehicles is predicted to take decades. As well as the technical constraints, a significant barrier is the hugely extensive sunk investment in non-automated vehicles and production capacity. The transition has been described in technical capability terms by professional institutions such as the Society of Automotive Engineers (SAE) (2014), which identifies a hierarchy of five levels of automation (Table 15.1). KPMG (2015: 10) reports a relatively cautious, if still ambitious, prediction indicating that just two per cent of the UK vehicle fleet would be fully automated by 2030, although 80 per cent are expected to be connected and 40 per cent achieving SAE Level 3. Approaching half of vehicles would therefore be equipped with features such as automated self-parking for urban areas and a high level of driver assistance on highways, although, critically, not to the extent of releasing the driver from the task of actually driving the vehicle. Highways are seen as the least complex environment in which to provide automation, due to the limited set of vehicle interactions and their exclusive use by motorised vehicle traffic capable of high speeds, followed by urban areas, where there is some segregation of flows on most streets. Road user interactions, particularly in shared spaces, remain problematic, and rural roads, with higher speeds than urban areas and often lacking pavements, represent the toughest challenge. Indeed, such are the complexities of rural environments that it is not certain that the entire existing public road network in all states can be made 'machine readable' (Stilgoe 2017).

SAE Level	Narrative Definition	Example(s)
1: Driver Assistance	The driving mode-specific execution by a driver assistance system of either steering or acceleration / deceleration using information about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task	Intelligent Speed Adaptation; Lane Keep Assist; Autonomous Emergency Braking
2: Partial Automation	The driving mode-specific execution by one or more driver assistance systems of both steering and acceleration / deceleration using information about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task	Traffic Jam Assist
3: Conditional Automation	The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene	Highway Autopilot; Valet Parking Assist
4: High Automation	The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene	Remote Parking; Urban Automated Driving; Low-Speed Autonomous Transport Systems without guideway but off public roads ('pods')
5: Full Automation	The full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver	Full end-to-end journey

Table 15.1. SAE definitions of automation levels. Source: SAE 2014.

Despite the uncertainties about when (and in some quarters *if*) Level 5 operation would be possible, the level of driver assistance features in cars already available to purchase is rising. By 2017, a growing share of new vehicles was already equipped with Level 1 and 2 features, and a small number of models featured aspects of Level 3. Whilst the latter were marketed as 'driver assist' features, there had already been high-profile crashes in which a key factor was the driver using the feature as temporary 'driver-replacement'. Similarly, connectivity was growing, with the European automatic emergency call system (eCall) to be present in all new vehicles sold in the continent from April 2018. The systems of a typical passenger car already collect a large quantity of data, which could provide dynamic information to a road system manager, once the legal, regulatory and infrastructure barriers are overcome.

For whom might CAVs matter most?

Despite strong government and industry support for CAVs, a review of public opinion surveys (Clark *et al*. 2016) found that US, UK and Australian respondents showed polarised attitudes towards autonomous vehicles, with half-to-two-thirds preferring a human-driven car. Notably, preferences were much more favourable in samples from industrialising states, reflecting the lower level of licence holding. By contrast, in the industrialised states at least, driver assistance technologies already have proven appeal for those who have acquired a driving licence and prefer to retain legal responsibility at all times for the motion of the vehicle, but would like to reduce the cognitive and physical load of driving. In addition to reducing the fatigue from driving, these systems are also relevant where drivers have limitations on their physical or perceptual abilities that are not severe enough to prevent them from driving, but could be ameliorated in conditions of, say, poor weather, low light or congested traffic. These features do not so much ‘drive’ the vehicle but provide information to the driver to ensure turning movements are safe, and provide warnings or apply emergency braking if a collision risk is detected. Fully automatic parking is already available on some models; parallel parking involves a set of manoeuvres that require awkward head-turning movements and distance perception, and thus older and mobility impaired motorists are seen as key beneficiary groups.

Another set of potential motorist-beneficiaries of automation short of completely driverless journeys would be those who travel long distances on motorways. Here, the restricted-access nature of the road, the relatively comfortable in-vehicle conditions and the more limited range of vehicle interactions compared to non-motorway travel mean that fully autonomous driving for specific sections of road in certain conditions is likely to happen early in the technological transition. The attractions of this feature would be to free up the travel time currently spent on driving a vehicle so it can be used for other activities, such as safe communication by telephone or with other vehicle occupants, working, reading, playing games or watching video. The demand from businesses in particular for ‘part-time’ automation is likely to be high, due to the potential for employee time to be used on more productive activities. Here, one early-adopter commercial sector is likely to be roadfreight, through the application of truck platooning (CEC 2017), designed to reduce heavy goods vehicle fuel consumption, although the challenges of integrating electronically-coupled ‘trains’ of large vehicles on highways busy with light, faster-moving passenger vehicles have yet to be resolved.

Public transport systems are a third emerging niche. Due to the defined nature of the routes in most current public transport business models, it is likely to be possible for Level 4 automation to be adopted earlier than a ‘go anywhere at any time’ application. Early experimentation (e.g. Citymobil undated, Citymobil2 undated) has focused on small-to-medium (four to twelve seat) vehicles, commonly referred to as shuttles or ‘pods’, in partly-segregated environments sharing space only with pedestrians, although projects with road-going vehicles are emerging. As pods are battery-electric, the operational distances are generally kept short, and currently speeds in shared spaces are typically kept to a fast walking pace to ensure safe operation. The market niches that have seen greatest focus to date include providing the ‘last-mile’ extensions from public transport hubs, within ‘campus’ facilities such as airports and business parks and in pedestrianised urban areas. With the rise in demand for special car access requirements by mobility-impaired people, such vehicles could enable full pedestrianisation whilst retaining access for all.

CAVs and sustainable mobility

The tendency for ‘smart mobility’ to be presented as much as a business opportunity as a transport efficiency opportunity is particularly true for CAVs. KPMG (2015), commissioned by the British automotive industry representation body The Society of Motor Manufacturers and Traders, identified a potential £51 billion worth of social and economic benefits by 2030 to the UK economy alone, derived from capital investment opportunities, job creation and road safety improvements. The business model under which such benefits would arise is not clearly articulated, although it tends towards one of ‘business as usual’, with most vehicles provided on an owner-user basis. Under these circumstances, some tendencies for more sustainable – if still car-dependent – mobility might arise. For one thing, the speed imperative may fall with autonomous driving. The optimal amount of time may no longer be the minimum travel time, but might instead become the time necessary to undertake a desired activity, such as to sleep seven hours, particularly in the case of a commercial driver requiring a statutory rest break, or matched to the length of a film a family wishes to watch together. The prospect of a greater variety of in-vehicle activities becoming possible may have implications for demand for surface public transport (and even short-haul air travel), but would enable road transport to operate at an energy and emissions-optimal speed. Moreover, the prospect of connected vehicles increases the likelihood that the road network will become an increasingly managed system: travelling at different times and perhaps at different speeds might attract differential pricing to match demand efficiently to capacity.

Many of the socioeconomic benefits of CAV use due to greater participation in society and the economy could be largely independent of the model of implementation. A blind person might travel independently to work or meet friends, with only remote surveillance of the vehicle cabin and environs and telecommunication with the occupants to ensure personal security and provide reassurance. Further, the wider adoption of CAVs within the public transport network is seen as an opportunity to reduce the cost of supply: driver labour costs in particular, but also energy consumption, wear and tear, and collision repairs. In the absence of on-board personnel, digital technologies will facilitate access, enable ticket validation and provide remote surveillance. A key potential of this development would be the opportunity to operate more, smaller, vehicles in lower demand-density environments, improving the penetration by public transport of suburbs and rural areas. Survey evidence from Bristol, however, indicated that over half of respondents would not use an automated bus, suggesting that the public remains to be convinced about the trustworthiness of the technology and not having personnel on board (Clayton *et al*. 2019).

At the same time, substantial risks to sustainable mobility can be identified if CAVs were introduced without an accompanying change in the relationship between the car and society. Removing the limits created by the current legal requirements for driving skills, satisfactory health and physical ability, and being fit to be in charge of a vehicle (sufficient sleep, absence of intoxicants) would be expected to release latent demand, particularly from those who can’t drive. Removing other deterrents, such as the requirement to find a parking space, or navigate and drive in unfamiliar locations, would increase demand from those who are uncomfortable with such things. In the highest-traffic scenarios, existing demand may be increased by travellers choosing to ‘summon’ and ‘send’ privately owned CAVs to and from their home bases to avoid parking constraints and charges at the destination.

It is also likely that an increase in CAV use would be associated with a fall in other types of travel, including walking, which would have health implications. Whilst 80 per cent of trips in the UK of under one mile are walked, there is a growing group, particularly older citizens, for whom walking is very limited. We noted above that one of the potential shuttle niches would cater for those with limited independent walking ability, but it might be practically impossible to reserve such a service for those who need, rather than choose, to use it. In a context of rising population obesity associated with declining physical activity (Mytton 2018), automated local transit might remove a key opportunity for exercise during the course of the day. If security questions are resolved, busy parents might see CAVs as an ideal way to send children to school, freeing them from the school run. This latter example does remind us, though, that many CAV benefits, such as social inclusion, will only arise once particular thresholds of technological development are achieved, to the extent that minors could travel unaccompanied without any traveller interaction with the vehicle being necessary. In the meantime, there is a risk that private cars with greater driver assistance will sharpen and increase the divide between those with and without car access in society: during the transition, assistance features will only be available to those with driving licences and car access, and these features will enable the ‘part-time’ driver, multitasking on the move, to travel further to take advantage of opportunities such as optimal employment, lower consumer prices, and attending signature cultural events, whilst for those without access to automated cars, the horizon, at least in relative terms, will recede.

Electric vehicles

The inclusion of electric vehicles as a feature of a smart mobility revolution may, on the face of it, come as a surprise. Electric power has been the dominant motive force for street and underground rail systems for more than a century, and has a significant share of general rail traffic in many countries, including 100 per cent of rail-km in Switzerland. By contrast, as a road transport power source, electricity has had a niche role since the invention of the motor car, for example for urban delivery rounds for products such as milk delivered to the doorstep. The factors that made electricity of interest to early road motor vehicle producers were similar to those that had appealed in street rail: a relatively simple and reliable technology that avoided explosive liquid fuels and without emissions from the vehicle. More recently these benefits have been accompanied by the additional energy (and therefore carbon) efficiency of EV systems over the internal combustion engine (ICE), namely reduced energy loss to heat and noise, the high torque meaning gearboxes are not required, virtually zero energy consumption on idle and the potential to recover energy during deceleration. These more advanced automotive technologies do, however, require complex on-board management systems to optimise performance, often married with ICE power sources in hybrid-power configurations. The on-board systems are connected to increasingly sophisticated 'smart charging' facilities to minimise charging time, themselves part of emerging 'smart grids' to ensure that a massively increasing demand for electric power can be met by the most efficient, flexible supply arrangements.

Several 'vehicle-fuel pathways' offer the potential for 'cradle-to-grave' greenhouse gas emissions (GHG) which approach half those of petrol-fuelled internal combustion engine vehicles (Elgowainy *et al.* 2016), although the greatest potential lies with hybrid, battery-electric and fuel-cell electric vehicles (FCEVs). Moreover, if electricity from renewable energy sources can be sourced, these combinations largely eliminate greenhouse gas emissions from vehicle operation. Hydrogen, whether used directly as an ICE fuel or to power fuel cells to produce electricity on-board, has been for decades the main rival to battery-electric vehicle (BEV) technology. Recently, in 2015, the first large-volume car manufacturer, Toyota, finally put a Hydrogen Fuel Cell Vehicle (HFC) into production. Although HFC technology avoids the refuelling and range problem that has until recently been associated with BEVs (a three-minute hydrogen refuelling can give up to 500 km range), it has a greater problem in requiring a novel supply network, whereas there is an established electric supply grid already. Moreover, there is the need to handle and compress an explosive fuel, although research to develop nanoporous materials to physically adsorb hydrogen as an alternative to high compression is ongoing (e.g. Noguera-Díaz *et al*. 2016). A more fundamental limitation currently is that HFC technology is mainly reliant on fossil fuel petrol as the raw material in a chemical process to produce hydrogen, whereas electricity is a highly-flexible storage medium for energy and has greater current potential for production from renewable sources. Most major automotive manufacturers are now developing BEVs as the 'smart vehicles' of the future, and they are therefore the focus of this section.

Electricity is now under development as a transport motive power source in applications ranging from the electric bicycle to the aeroplane. Hybrid human / mechanical power in the e-bike extends both the possibility of cycling to a wider population, and the range of existing utility cyclists. The emergence of electric aerial vehicles is most obvious in the case of drones with a range of applications from remote sensing to deliveries, although commercial, long-range electric passenger aviation remains a very long-term prospect. The limitation on the expansion of the EV road vehicle was the lack of a practical equivalent to the ground or overhead supply infrastructure that make electric railways so effective. It is only in very recent years that this fundamental barrier has started to fall. The electric vehicle problem is a nexus of the technical capabilities of on-vehicle storage solutions, the commercial cost of such technologies, the availability of recharging infrastructure and the speed of recharge. For decades, automotive batteries were heavy, low-performance lead-acid capacitors requiring overnight trickle charging. The main weight of a battery delivery vehicle was the batteries. The range of electric cars was typically limited to around 100 km, with a sharp trade-off between range and acceleration or cruising speed. Such performance would only be adequate for a car used exclusively for short-range journeys, perhaps as the second car in a household. Early adopters were encouraged to modify their driving styles and would need to make alternative arrangements for medium or long-range trips.

Far more appealing in most markets were the hybrid vehicles that originated in Japan in the 1990s, initially using electric power to replace the ICE at low speed, and to assist it at high speed, but subsequently acquiring 'plug-in' capacity. In this more recent guise, a hybrid operates as a rather heavy and complex EV for most trips, but with the capacity to revert back to traditional ICE technology on longer trips, once the battery is exhausted. Of note here is the case of Norway, the BEV market-leading state by far, where, in 2015, EV sales exceeded 15 per cent of market share. This was achieved in the context of taxation policies that meant the 'total cost of ownership' of an electric car had fallen below that of an ICE car, and a number of incentives, which variously include parking fee and toll exemptions and the possibility to use bus lanes (Bauer 2018). The Norwegian case exemplifies at once the impact that a clear set of policies backed by public sector funding can have on consumer attitudes and behaviour, but also the scale of the transition. In 2017, sales of electric and hybrid vehicles exceeded 50% market share for the first time (Knudsen and Doyle 2018), but 79 per cent of vehicles sold still contained an ICE. Initiatives to further the consumer appeal of EVs, particularly in states where government fiscal incentives are less (or not) available, fall in to two broad strategies: further enhancement of battery technology and innovative means of recharging.

By 2017, it could be argued that for the five per cent or so of car purchasers seeking at least an 'executive' model, the EV 'problem' was effectively solved, through the emergence of production cars priced by range, acceleration and other performance features, with a 400km car retailing at around $85,000 and a 600km car nearly twice that price. Moreover, recharging facilities allowed these electric 'supercars' to 50 per cent recharge within 20 minutes and fully recharge in an hour. As safety advice for long-distance driving in any case advises breaks of 15+ minutes every two hours, provided that sufficient recharging facilities were available the electric car has now become an option for long-as well as short-range trips. The focus of the challenge has thus been shifted from absolute technological limitations to constraints on mass-market commercialisation. By 2018, prospects for a 35-40 per cent cut in the price of lithium-ion batteries seemed high (Lambert 2017, Schmitt 2017). Such a development would facilitate the $35,000 electric car, although this would only represent one further step towards a genuinely 'economy' model.

Alternative solutions to the battery range problem have focused on different means of recharging, rather than increasing battery capacity or achieving faster charging rates. A long-established option for vehicles in industrial use is to swap a discharged battery for a charged one. Development of this technology reached a modern high point in 2012 when the US-Israeli firm 'Better Place' began pilots in Israel and Denmark. The technology proved effective, in that a battery swap could be accomplished in less than five minutes, competitive with the time to replenish liquid fuels. Within a year the company was in liquidation, however. Two factors that contributed to the failure were inherent to the business model. First, was a specific incidence of a general problem for transport technologies that major investment is required upfront to establish a network of sufficient scale, in this case to attract users who wished to use electric cars as flexibly as they did ICE cars. Second, was the difficulty of attracting car manufacturers willing to accept battery standardisation to the specification of a small start-up, and in practice only a few agreements were signed (Gunther 2013). Given that much of the charging was in any case expected to have been done at home, the advent of fast-charging facilities at highway rest areas means that the case for the battery-swap approach now seems to have largely disappeared.

Other innovative approaches to charging are still at the developmental and pilot stage, but seek to extend vehicle range on highways through charging on the move. One approach is to take the trolleybus principle and apply it for hybrid-power heavy goods vehicles on highways, with the trucks using diesel power away from the pantograph. A 2km trial facility already exists on a Swedish highway (Mendelsohn 2016). A number of national highways authorities worldwide have also explored wireless inductive charging technologies for a range of vehicle types. The up-front cost of providing the infrastructure underneath the road surface might be part-justified by the potential to charge for associated services, notably access to a priority lane, but electromagnetic leakage problems would need to be resolved (TRL 2015).

EVs and sustainable mobility

In common with all transport systems, production of and provision for EVs requires raw materials. FCEVs are dependent on platinum-related metals as catalysts, but they are already used within ICE vehicle exhausts, the demand for which can be expected to decline as EV adoption grows (Blue Quadrant Capital Management 2017), meaning there is unlikely to be a platinum scarcity for FCEVs. The battery-technology of BEVs, instead, is crucially dependent on lithium. Whilst lithium is not a rare commodity, there are logistical constraints on securing sufficient high-quality lithium at a viable price (Narins 2017).

Changing demands for raw materials for automotive production is just one factor that suggests that, whilst BEVs and rival technologies offer great potential, achieving the theoretically-described transition presents major technical and political challenges. In practice, as Greene and Parkhurst (2017) concluded, the international climate change policy commitments for emissions reductions by 2050 will not be achieved without behaviour change measures to mitigate greenhouse gas production as well as technological development. Paradoxically, however, the whole commercial basis of the technological development is to minimise the necessary behavioural, cultural and economic adjustments. Further complicating matters, without significant behaviour change, technology substitution can result in ‘rebound’ effects, whereby cost reductions lead to higher consumption of the same or other goods and services (Bjelle *et al*. 2018). Direct rebound effects arising from the relatively high EV capital costs but lower running costs compared to ICE vehicles, could lead to higher annual distances travelled and in the short-to-medium-run contribute to rising traffic and congestion, which in turn would slightly worsen the performance of the existing ICE fleet.

Sustainable mobility is not solely about reducing climate change impacts, important though those are. A clear benefit is that toxic exhaust emissions from vehicles are much reduced by a switch to EVs, albeit that ‘zero impact’ claims require some caveats. For a start, EVs continue to have negative impacts on air quality because of particulate emissions from the wear of vehicle components such as tyres and brake friction surfaces. Being heavier than ICE equivalents, those non-exhaust emissions can potentially be higher (Timmers and Achten 2016). In relation to noise pollution, far quieter operation does offer a benefit to the public realm, particularly at slow speeds in urban areas, although both the US and EU have mandated that new EVs from 2019 must emit a sound sufficient to enable pedestrians to be aware that a vehicle is being operated. And EVs require additional ‘street infrastructure’, in the form of recharging points and cables, so will tend to add to the overall consumption of street space by road vehicles, as well as increasing their visual intrusion. EVs emerge as an important mitigation-technology for some of the negative effects of car use, but do not, in themselves, entail a sustainable transport system.

Digitally-enabled collaborative mobility

The sharing of transport assets in time or space by unrelated citizens, formal or informal, on officially regulated transport services or those operating beyond the law, has always been a feature of the personal mobility system. In the industrialised democracies, though, sharing as a formalised, sanctioned practice – that is, promoted or even managed by public bodies and often attracting public funding – has hitherto tended to focus on public transport systems. The growth of smart media and an 'always on' digital infrastructure have revolutionised, in three decades, the way people communicate, socialise and access data-based services, and there is reason to suppose that travel behaviour might be more subject to change now, than in recent times. Several initiatives have emerged to promote and exploit this potential. The public sector has been active in promoting higher-technology integrated ticketing solutions to render collective transport solutions more attractive and easy to use, whereas the private sector has sought to develop 'ridesourcing' and 'Mobility as a Service' solutions, some of which offer the potential of more collaborative, and therefore potentially more sustainable, solutions.

The digital integration of transport through MaaS

At the core of the digital transport revolution is accurate and dynamic (real-time) travel information. From this perspective, the citizen-on-the-move requires information 'now', and expects to get it immediately, whether in the home or other location, or travelling, and often without speaking to another person. It was not so long ago when the location of buses, trains and trams remained the domain of specialist staff in operational depots or call centres, but GPS, enhanced signalling and 4G technology has revolutionised this in a very short timescale. Although real-time information provision remains patchy in extent and reliability, often travellers with the relevant 'app' available on their portable digital technology can be notified if a particular bus is running five minutes late for a usual trip home, or enable the booking of a table seat with a window on a train departing in two hours' time. It is from this 'digital' perspective that the concept of MaaS emerges. The term MaaS is in fact used variously (Jittrapirom *et al*. 2017), with some authors restricting its application to services which may be provided by different operators but bundled together into a service contract with a consolidating organisation (Holmberg *et al*. 2016). Here, though, we use the term more generally, to cover various means by which public transport can be integrated with transport services such as taxis, car share, car hire and cycle hire, to deliver a seamless service for a consumer to access his or her mobility needs.

Such has been the technological development that the barriers today in the transition to effective MaaS solutions are not in reality IT related, but are a manifestation of the governance of mobility policy. It was EU directive 91/440 in 1991 that structured a trend in the industrialised democracies for the state to disaggregate itself from both the direct control and operation of public transport services. Great Britain is an extreme case, with its total deregulation of buses outside London, removal of state intervention powers on service coordination, and franchising of trains on the former British Rail network. The outcome of this policy approach is the creation of isolated, closed bus networks and systems at a company level. Passengers are sought as exclusive consumers, with operations, ticketing, fares and information systems deployed to achieve that end; hence functioning directly in conflict with the open and collaborative principles of MaaS. Just the matter of persuading bus companies to work together to provide a simple multi-operator ticket can be a highly complex and protracted process.

Yet public transport consumer mobility needs are rarely *inherently* so exclusive, and nor is such loyalty willingly given. Indeed, a common desire of travellers is to have access to sufficient information about a range of travel modes and service providers, so as to be able to decide which will allow them to reach particular destinations, at the most suitable time, for an acceptable price and at desired levels of comfort and service reliability (Lyons 2006). Central to these motivations is the ability to capture core data in a standard form for comparison of options and product delivery. This, of course, is neither revolutionary nor new. In 2000, the UK launched *Traveline*, a national phone number and internet service for local passenger transport journey information, delivered through regional consortia on the instruction of the national government. *Traveline* acted as a key conduit for the standardisation of timetable information through a new data standard, transXchange, which has led to a national passenger transport timetable dataset, updated regularly, as an accessible national resource that is at the heart of most British journey planning apps and real-time information systems. However, whilst commendable in a deregulated market (albeit the UK national dataset only exists because of state intervention), after almost 20 years, *Traveline* is still unable to inform customers how much it will cost to go to town on the bus. Whilst the UK does indeed have a complex structure of ticket types and options within a deregulated market, there is no *technical* barrier which would prevent a process for storing and updating such information. Why this has not happened remains an ongoing matter of debate (with a new consultation on future data standards, provision and responsibilities underway at the time of writing).

Indeed, alongside information, electronic ticketing is the other key aspect of the digital transport revolution. In the UK, the technical solution to operator-led closed ticketing systems that restrict opportunities for multi-operator products was ITSO, a national standard for multi-operator ticketing (ITSO undated). ITSO is an open ticketing standard based on global banking data protocols, defining how ticketing messages are exchanged in a secure, encrypted manner, enabling a customer's purchase and use of a product to be identified and associated with payment apportionment. As an open standard, any supplier of ticketing equipment can develop a product and have it certified by ITSO as meeting the requirements to support multi-supplier data exchange. This specific issue of payment validation and apportionment is at the heart of the opportunity for IT to exploit MaaS in a deregulated sector. As we consider later in the section, 'transportation network companies' (TNCs) such as Uber and Lyft successfully exploit the IT infrastructure through providing a shared access and payment platform between the consumer and the provider. Payment is agreed in advance and is unique per trip based on time of day, distance, vehicle type and even the level of demand versus supply at the time of booking. There is limited risk of a customer over-riding without extra payment, as the journey data is captured and remunerated in full.

In a deregulated passenger transport network of driver-only buses with multiple doors and a limited number of revenue protection officers, and non-gated local rail and tram stations, the ability to capture the journey data and reimburse fairly in accordance with an operator's business rules is critical to MaaS acceptance. Assuming both journey and fare information is available, how can barriers be overcome and opportunities realised in multiple closed-system areas? In addressing this question, we need to recognise that the last decade has seen a genuine uplift in the capability of in-vehicle ticketing equipment for taxi, bus and rail systems, all exploiting GPS and 4G communications. Within the bus sector, the transition from solid state Electronic Ticket Machines (ETMs) to on-board computer-based ETMs is almost complete. Three existing IT platforms already exist to exploit these new ETM capabilities using open standards to support multi-operator closed systems: contactless bankcard payment linked to account based ticketing, barcode ticketing and smartcards.

At the time of writing, contactless payment (cEMV) on buses was in the process of being widely introduced across UK bus networks, as in many other parts of Europe. Eliminating the need to carry cash provides a clear customer advantage, as does the ability to use third party payment apps such as Apple Pay or Android Pay. Still, cEMV does retain inherent challenges for MaaS delivery. First, outside of London, on-bus cEMV is only being used as a payment platform. For a ticket purchase up to £30 in value a paper ticket is issued; lose that paper ticket and there is no 'insurance' – the traveller must pay again. In addition, 'smart ticketing' has not achieved fare capping across modes and operators outside London. Fare capping is a politically desirable and popular charging practice that means no further charges are accrued once a certain amount has been spent in a defined period. Whilst account-based ticketing can be introduced outside London, enabling an individual customer's total spend to be capped at a fixed daily, weekly or other rate, this has in practice only been achieved at the level of a single operator (corresponding to a single 'finance key' embedded within the ETM). So, as of 2018, 'multi-key' capping across a defined area outside London was not available: multimodal and multi-operator tickets were available on a fixed-price rather than variable-with-cap basis, meaning they were more likely to be attractive to travellers able to plan ahead and with a high level of knowledge about ticketing options.

Barcode ticketing offers a relatively cheap platform for multi-operator product issuing and revenue apportionment by product. ETM infrastructure add-ons are relatively low cost, and products can be hosted as paper tickets or on mobile devices. Like the pre-ITSO days of smart ticketing, however, the bus sector has not agreed to support one particular barcode standard, meaning the ability for the product to be read across multiple operators is not guaranteed. Lastly, smartcard ticketing using a defined standard such as ITSO remains the safest and most secure platform for open area multi-operator ticket retailing, ensuring full product business rules can be applied, data to support accurate revenue apportionment captured, and customers supported if a card is lost or stolen. But there are costs associated with card-based infrastructure and product vending. A hybrid of full ITSO security embedded within a phone app, enabling instant ticket upload, delivering full ITSO messaging to each Terminal using the phone's Near Field Communication capability and available as an open platform for all, is currently being developed between ITSO and a major internet system provider. If successful it has the potential to deliver a real opportunity for any MaaS or other provider to be able to offer multi-operator passenger transport in an open-system environment.

Thus it is not IT that is a barrier to a wider customer proposition of accelerating change in mobility behaviour, but the required adoption of existing standards to provide the core data upon which opportunity is built. With bus patronage in all deregulated areas of the UK in decline for most of the last three decades, and London the only regulated and genuinely integrated area experiencing continual growth, how long can a failed model of ineffective national policy on the application of data standards and weak local governance be tolerated if shared passenger transport is to have a future? After all, it is well established that the introduction of multimodal and easy-to-use ticketing options can increase public transport use, even if part of that increase is often explained by an effective reduction in fare levels if there is a maximum fare price cap (Balcombe 2004) and additional usage alone rarely covers the costs of investing in new ticketing systems (Shergold 2016). Smart ticketing investments do have wider benefits, though, including better system usage data for the operator, and although Shergold did not identify evidence that smart ticketing in itself is the key factor in mode switches from car to public transport, a supporting and facilitating role in modal shift to help promote more sustainable mobility remains very plausible.

A widening range of mobility services

In the highly-industrialised states, transport provision has generally exhibited a sharp divide between private and public systems, with public transport services generally running on fixed routes and schedules, using medium or high capacity vehicles, and being professionally managed and delivered. In recent decades, though, these states have seen a growth in both the range and magnitude of mobility options involving both the shared ownership and the shared use of assets such as cars, bicycles and taxis. Digital technologies have underpinned these new ways of owning and using mobility assets, by enabling the provision of information, the completion of transactions, and managing the physical access to assets for a low cost, for example, because operational staff do not need to be present.

In the case of cars, it is possible to categorise a growing diversity of ways in which cars can be owned and used (Table 15.2). Informal sharing remains an important practice in specific communities and types of geographical area, such as amongst urban ethnic minorities or in rural areas with limited transport alternatives. More generally, however, rising wealth has permitted most households to own one or more private cars, and sharing generally became limited to people in the same households, families and friend groups. The decline of casual hitch-hiking is one example of this change. Recent decades have, though, seen the emergence of car-sharing schemes – which provide members with pay-on-use access to cars which are owned by private, public or third-sector organisations, sometimes referred to as 'clubs' – and car-pooling – regular arrangements by which car owners driving to a location offer unoccupied seats to people travelling to the same location, such as work colleagues, on a not-for-profit basis (Cairns and Harmer 2011). These practices are now institutionalised as policy measures enshrined in processes such as the EU Sustainable Urban Mobility Plan initiative (e.g. Wefering *et al*. 2014). Rather than being secured through word-of-mouth 'micro-agreements', employees are now encouraged to find car-pooling partners with the aid of geospatially-linked databases of likely suitable colleagues. Preferential parking and other incentives support this 'behaviour change' (Litman 2016). Car-sharing instead provides a rational solution for the household which desires some access to a car, without the high cost per journey of hiring a taxi, but does not want to be subject to the social control, precariaty and exchange constraints which seeking assistance from a relative, friend or neighbour who has a car might entail, particularly if the need is frequent or routine (Chapter 12).

<table>
<tr><td></td><td></td><td colspan="4">Shared with:</td></tr>
<tr><td></td><td></td><td>No-one</td><td>‘Known’ others e.g. friends, acquaintances</td><td>Strangers</td><td>Clients</td></tr>
<tr><td rowspan="5">‘Ownership’ for periods of:</td><td>Hours</td><td>Car-sharing
A2B / A2A</td><td colspan="3" rowspan="2">Ways which combine shared ‘ownership’ with shared access, often with facilitation through online mobility brokerage platforms</td></tr>
<tr><td>Days</td><td>Traditional Car hire
P2P car hire</td></tr>
<tr><td>Months/ Years</td><td>Leasing</td><td rowspan="3">Informal car-pooling with work colleagues
Formal car-pooling with colleagues or near-colleagues</td><td rowspan="3">(Traditional hitch-hiking)
‘Lift share’: virtual hitch-hiking not-for-profit</td><td rowspan="3">Traditional Taxi
Deregulated ‘Smart Taxi’</td></tr>
<tr><td>Flexible</td><td>Mobility as a Service packages</td></tr>
<tr><td>Full time</td><td>Traditional ownership</td></tr>
</table>

Table 15.2. Diversification of car ownership and access niches. New forms shown in italics; disappearing form in brackets.

Two features characterise the resurgence of shared mobility. First, it is not motivated primarily by the limited personal spending power of the traveller. Instead, sharing results from consumer decisions in which cost is only one of a complex range of factors. These factors have been linked to new types of lifestyle. For example, Rayle *et al*. (2016) found that ‘ridesourcing’ services such as Uber and Lyft had a special appeal for a group of generally younger, well-educated urban travellers with a high value of time; ‘special’ in the sense that the offer was not replicated by other modes. Second, the rise of information technologies applied to the mobility sector has made such services both more attractive to users and possible for providers (Enoch 2015). Labour costs have been avoided, for example, by the provision of automatic rather than staffed cycle hire from docking stations in the street. Internet-connected vehicles and docking stations enable real-time information on the availability of assets for hire, and booking and payment systems to secure them remotely. The rise of automation may also favour shared mobility if the links between vehicle ownership and use are further weakened by the car becoming more utilitarian and less an expression of socioeconomic position and less influenced by emotion (Steg 2005). Chatterjee *et al*. (2018: x) observed that reductions in car use amongst UK adults born since 1964, compared with those born in the period 1946-1964, have been “influenced by a long-term increase in the age at which people typically start working, begin relationships and have children.” The same authors concluded, however, that this reduction could only partly be explained be deterrent economic factors such as transport costs, and that attitudinal survey evidence indicated greater acceptance over time of lifestyles not orientated around the car (Chapter 14). It seems, then, that the attitudes and behaviours of current young adults will, overall, reflect weaker attachment to the car in later life as well, although with variation within that group according to lifestyle choices and circumstances, and to some extent showing greater engagement with the car later in the lifecourse.

Will collaborative mobility enhance sustainability?

Given that shared mobility is altering social practices, creating new economic opportunities (whilst potentially undermining others) and encouraging different ways of being mobile, in most cases with traffic, energy and emissions consequences, does the greater sharing of transport assets necessarily promote more sustainable mobility in its broadest sense? Does it offer the potential for revolutionary change? Or is it, as Martin (2016: 149) suggests, just “a nightmarish form of neoliberal capitalism”? The most established TNC based on a digital platform is Uber. Like other platform based companies, Uber has been criticised for its labour conditions (e.g. Lawrence 2016), but focusing on transport service considerations, three key concerns have been emerged. The first is that Uber may result in a decline in service standards by circumventing regulations which may not concern the traveller at the point of purchase, but exist to protect the public, the public interest or minorities. In practice, whether Uber threatens regulations will tend to depend on the specific local ordinances on taxi regulation. In the UK, for example, Uber operates as a ‘private hire’ service which is the form of pre-booked taxi with a less onerous form of regulation. It cannot operate as a ‘Hackney Carriage’, so does not benefit from the advantage of using on-street ranks, but at the same time avoids more onerous regulations, such as using fully-accessible vehicles, a specific livery or meeting particular emissions standards. Since app-hailing represents greater competition for the street rank than pre-booking by phone, however, it may indirectly make higher-regulation services less viable.

Second is the concern that TNC companies will compete with public transport, on which some citizens, for whom ‘ridesourcing’ services are not suitable or too expensive, are dependent. A consequence arising might be the need for greater public sector support to maintain public transport networks. Here, the evidence is provisional. Hall *et al*. (2017) concluded that, for US metropolitan areas, there was considerable variability on the impact of Uber on transit services, but on balance they found a complementary effect. Greater research into these phenomena was, at the time of writing, necessary.

Third is the more subtle concern that Uber is conceived by transport sector policymakers and professionals as a ‘shared’ service, because it may be a factor in some users not owning their own cars, and because it has a shared-ride variant. Uber (Personal Communication) has stated that around half of its customers in downtown San Francisco were choosing its Uber Pool service in 2018, each paying perhaps half as much as the exclusive-use fare. But the potential for intensive ‘synchronous’ sharing of flexible route and schedule TNC services remains very much a potential rather than a reality. Uber Pool is not available in all jurisdictions, and then only in certain large cities in those countries in which it is offered. The conceptual attractiveness of an urban mobility future in which sharing becomes the social norm has been demonstrated through scenario modelling studies, but with important caveats. In the case of Lisbon, for example, the International Transport Forum (ITF) (2015) showed that an exclusively-used (asynchronously) shared CAV fleet would only be 23 per cent smaller than an unshared fleet providing for the same level of mobility, but traffic and peak congestion would double, due to the repositioning of empty vehicles. A fully synchronously-shared fleet could be much (90 per cent) smaller, but even here, traffic and peak congestion would show modest increases of six and nine per cent respectively.

All of these findings underline the ongoing importance of high-efficiency, traditional public transport routes on principal urban corridors, with users walking modest distances to access the services, implying that to some extent a mixed-mode ecosystem would need to be retained. It is also worth pointing out that all such studies rely on the very important assumption that citizens will share small vehicles with strangers – significant psychological barriers to sharing will remain even if the practical ones are effectively overcome (Merat *et al*. 2017) – and also that the applicability of the shared mobility service models outside of densely populated urban areas will be subject to much greater viability constraints.

Smart mobility: more than an investment opportunity?

In summary, the analyses of the previous three sections indicate that:

- The benefits of CAVs are highly uncertain, both in terms of extent and evolution, and considerable disadvantages are foreseeable, with the balance between the two being highly dependent on the socioeconomic and policy context in which CAV technologies are applied.
- Electrification of the road vehicle fleet is a necessary but not sufficient condition for more sustainable mobility, with some unintended consequences and uncertainties in relation to the rate of substitution and importance of rebound effects on traffic and overall energy consumption.
- Digitally-enabled mobility is technically quite feasible even if it continues to face considerable regulatory, institutional and financial challenges. Enhanced information and easier ticketing options are also desirable from the traveller’s perspective, provided the technologies are accessible to all.
- Collective mobility is the development which can potentially have the greatest impact on the sustainability of our future mobility, and indeed of the four is the sufficient condition for sustainability, but at the same time is apparently the perceived transition which is most dependent upon faith: that citizens will alter both their travel and social behaviours to share small vehicles with unacquainted fellow travellers, even though exclusive-use travel options remain in affordable reach.

The uncertainties that emerge with each of the four technological shifts we have reviewed contrast with the certainty and appeal of the smart mobility discourse; the evidence behind the aspirations is largely based on assumption and scenario. In this context it is tempting to dismiss the claims of smart mobility protagonists as just another example of the conflation of technological innovation with ‘progress’, and ‘progress’ with ‘improvement’ (Bimber 1990). If the rhetoric identifies the ‘future conditional’ as ‘smart’ or ‘intelligent’ then, by implication, traditional mobility arrangements are not only an ‘imperfect past’, but ‘unintelligent’ if not ‘stupid’ and are to be replaced. In the transport sector, however, ‘progress’ has generally been associated with increases in distance, capacity and speed, and the perceived spatio-temporal shrinking of the globe: in short, technical innovation has underpinned the long-run trends that many commentators now identify as being central to ‘unsustainable transport’ (Banister 2005).

The enthusiasm for ‘smart mobility’ also needs to be seen in the context of economic interests, and its emergence in a period of economic decline. Some commentators on recent economic performance regard the decade of austerity which began in 2008-09 as just another low-point in the economic cycle, and identify new technologies as a means through which capital can ‘reinvent’ itself to once again ‘create’ value, encourage investment and promote growth (Chang 2014), leaving some traditional transport systems redundant in the process. In their place rises the ‘platform capitalist’ (Srnicek 2017) business model of asset-light, information-rich software, extracting value from knowledge about the locations of travel demand and operators with assets well positioned to serve it, and from the labour involved in the processes of both information creation and provision of the service. The new ‘transportation network companies’ are perhaps the signature exemplars of this new business model. What remains very uncertain is whether the stock market valuation of Uber – the highest-value private technology company at the time its worth peaked at nearly €70 billion in February 2017 (Abboud 2017) – reflects long-term viability, enthusiastic (possibly over-enthusiastic) belief in the potential by the investors, or simple speculation, in the context that, at the time of writing, the company had yet to return a profit.

Others commentators, however, identify a different kind of emergent capitalism, a ‘fourth wave’, or go so far as to refer to ‘post-capitalism’ (Mason 2015). This latter thesis posits information technology not simply as ‘just another outlet’ for moribund capital seeking higher profit, but instead, asserts that the nature of the new technologies themselves are part of a fundamental change in economic behaviours. Indeed, other manifestations of smart mobility, emerging alongside but in contrast to the

TNCs, apparently defy established capitalist logic. According to the primacy of the market, there is no economic basis for the sharing of open source and free-to-access geospatial information and travel planning tools via the internet (Mason 2015). Nonetheless, services such as the journey planner for cyclists 'CycleStreets' are free to use. CycleStreets (undated) has operated for more than 10 years as a not-for-profit company. It makes use of voluntary software coding labour, with the only revenues being from donations. And some aspects of smart mobility may literally be a 'driving force' towards post-capitalism. Automation across the economy is predicted to reduce the costs of production by replacing waged labour, but the difference between the value created by human labour and the wages paid to workers has traditionally been an important source of profit, which, under automation, would disappear. From this perspective, whether goods and services, including transport services, remain viable as for-profit activities in an automated economy will depend on whether investors are willing to accept long-run returns on the value of high investments in automation equipment, or are able to rely on other sources of profit. These other sources of profit might include the value of a brand or, where businesses do indeed manage to exert proprietary rights over datasets, the extraction of value from information.

Hence, the transport sector emerges not only as a hotbed of innovation, but as a key 'foundry' for new economic alchemy. In this context of experimental uncertainty, the role of public policy emerges as critical: there is little doubt that 'smart mobility' will bring important changes and this will include changed networks of policymaking, with different actors controlling aspects such as information about travel demands and influencing service delivery in time and space. If the public good is to be protected in this new context there will correspondingly need to be a new regulatory framework with sufficient powers, and likely new forms of intervention in the market (Docherty *et al*. 2018). Such a public policy framework needs to be wide-ranging and flexible, too, not least because the simultaneous emergence of the four technological trends creates interactions between them. BEV technology can be more efficient if applied in a CAV context, because a managed operating system can maximise battery range and life through optimised driving and charging. DEM services facilitate collective mobility through reducing the transaction costs of payment and increasing the chances that attractive synchronously or asynchronously-shared travel opportunities are included in a MaaS suite. Similarly, DEM services can enhance EV use by providing information and securing access across the recharge facilities of different operators. And potentially most fundamentally, automation, by reducing operating costs and providing a high-quality passenger experience, opens up the possibility that access to a fleet of highly-available taxis may be sufficient to weaken the attraction of car ownership, and in turn that intensive use will result in faster turnover of a (reduced) vehicle fleet, enabling swifter technological upgrade in the future.

The extent and depth of change such development would entail, though, should not be underestimated. Whilst the other three trends can be potentially assimilated within the socioeconomic status quo, CM can only play a significant role if along the way it is associated with the scale of traditional light vehicle production being reduced to a fraction of current demand and advertising for personal vehicle ownership, currently one of the highest-spending sectors, largely disappears, along with the service industries dependent on mass car ownership, such as auto-retail, servicing, insurance and valeting. But only in the case of synchronous sharing does that change in ownership behaviour become traffic-reducing, rather than traffic generating: without sharing-in-use, vehicle-km travelled must rise in providing an exclusive-use taxi service equivalent to owner-driver trip-making. And here emerges a key and paradoxical discord: if many citizens are already reluctant to share with strangers, research into attitudes – at least current ones – suggests this reluctance becomes clear resistance in the absence of the authority of a human driver as a result of the role being automated (Clayton *et al*. 2019), and it is debatable whether remote surveillance by camera will be an acceptable alternative to a human presence in the vehicle. Hence, combining psychology and economics, CM emerges as potentially the most divisive, disruptive and challenging of the four phenomena. Mobility policy would be critical in 'cracking' this conundrum, through a package of financial incentives for sharing, traffic management priorities for shared services, and appropriate remote security and passenger support facilities. Even so, new small vehicle designs intended for sharing by unacquainted travellers and changes in social norms and expectations are also likely to be critical in enabling these emergent practices.

Meanwhile, in considering for whom the smart mobility revolution could matter, and how it could matter, it is clear that there will be an ongoing need to tackle established, mobility-related social inequalities, for example, in the context of shared-ownership mobility (Clark and Curl 2016). Even if smart mobility results in a fall in operating costs per unit of passenger transport service offered, that may not result in a fall in user costs, particularly if the reductions are reinvested in higher quality, or more extensive, services. Indeed, one pressure for more extensive services will arise from lower density suburban and rural areas within which traditional public transport has shown decline over many years, although it remains unclear how far the efficiencies and cost reductions of collective automated transport would be revolutionary, rather than marginal, outside of the metropolitan areas.

Without an inclusive transport policy and successful promotion of CM, then the possibility of those with sufficient means deserting public transport in favour of personally owned and used electric CAVs opens up a potential nightmare scenario for those dependent on traditional bus services (unless the state then contracts inefficient personal CAV travel for them as well). The wider socio-political consequences of such a scenario can only be telegraphed here, but might include further pressures for low-density development in a context of declining travel costs, and a cranking-up of the public health crisis if transport services are ever-more door-to-door, or even terminate within buildings. Despite the many challenges and paradoxes, however, just suppose a different ‘psychology of the car’ proves possible: the future really could be one mixing ‘active’ with ‘passive’ mobility, with the later provided by quieter vehicles with zero local exhaust emissions, connected so that they become production and consumption spaces on the move, rented by the hour rather than owned, and often also shared, and being reliably, carefully, and respectfully self-driven, ending the culture of the car as apparatus for the social display of aggressive or arrogant driving ‘prowess’.

In short, in smart and revolutionary times, transport policy matters more than ever.

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