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THE MANY ASSUMPTIONS ABOUT SELF-DRIVING CARS – WHERE ARE WE HEADING AND WHO IS IN THE DRIVING SEAT?

Graham Parkhurst

Centre for Transport & Society, University of the West of England

Glenn Lyons

Centre for Transport & Society, University of the West of England / Mott MacDonald

1 INTRODUCTION

There are currently intense – but contested and debateable – positive expectations about the adoption of Connected Autonomous[i] Vehicles (CAVs): most motor manufacturers are strongly engaged in their development; national and local governments are pursuing facilitative research and legislative/regulatory change; academics are densely populating conventions such as the US Transportation Research Board with presentations on both the technology and its implications. In the age of social media, the scope for hype has never been greater.

In this paper we examine the remarkable sense of inevitability surrounding CAVs as a policy-transformative technology; a phenomenon that exists despite the uncertainties facing societies around the world, both concerning CAVs themselves and the social, technological, economic, environmental and political context.

It is remarkable how rapidly the era of CAV expectation and development has come about and, in such a short space of time, how much literature has emerged. This is symptomatic of a number of factors which we will touch upon further; it also reflects the highly connected nature of society at a global scale. This provides a platform for innumerable commentators to offer perspectives. News spreads more quickly than ever before regarding progress, difficulties and speculation. Such connected thinking may be contributing to enhancing the pace of development but, and perhaps in greater measure, is contributing to hype. Uncertainty is characteristic of the CAV agenda. Accordingly, informed opinion, educated guessing and bias (conscious and unconscious) strongly characterise literature and commentary seeking to help chart the way ahead for a CAV future.

We seek in this paper to make sense of this. However, it also becomes appropriate for the reader to have some insight into the position from which we offer our own contribution. We draw upon our experience in examining socio-technical change in pursuit of understanding and influencing travel behaviour in the context of such change. This includes addressing the implications of technological innovation from two perspectives: transport technologies influencing the wider social and economic context; and innovation outside the transport sector affecting travel behaviour and transport activity. Specifically, we draw upon work with and for the New Zealand Ministry of Transport, Transport Scotland and the UK Department for Transport in handling uncertainty (Lyons), social research undertaken in three Connected Autonomous Vehicle (CAV) projects[ii] (Parkhurst) and a recent study[iii] for the UK Department for Transport into public attitudes towards new transport technologies in the road sector (Parkhurst and Lyons).

These experiences inform our scrutiny of literature from the academic, consultancy, and government domains with a view to understanding, interpreting, and critiquing how pathways of forward development and end states are envisioned and what shaping forces (and actors) are recognised, or overlooked, as being influential. The extent to which uncertainty is acknowledged and addressed and the distinctions between preferable (value laden), probable (assumption laden), plausible and possible futures are appraised.

The paper provides - or at least has aimed to provide - a balanced assessment of the real potential for automation as a transformative transport technology, accounting in particular for the path-dependent aspirations, vested interests and influences of the different types of actors involved. The paper focusses primarily on a discussion of road passenger transport automation, although some of the literature cited is also concerned with road freight transport automation.

2 POLICY ENTHUSIASM FOR ROAD TRANSPORT AUTOMATION AND CONNECTIVITY

The sociological institutionalist approach to understanding policy formation, delivery, and eventual reformulation emerged in the 1980s as a perspective of particular relevance for fields such as economic geography and urban and regional planning (Vigar, 2002). It holds that organisations, institutions and ‘institutionalised processes’ play a key role in shaping policy ideas. Social interactions between networked professionals are critical for each actor’s construction of an individual perspective on a problem, so that a ‘policy community’ can develop around a common understanding. Informal rules can be as influential as the formal rules about policymaking. Such a perspective underlines that knowledge is relational and somewhat subjective, and that values expressed can be institutional-organisational, rather than personal, whilst an individual’s beliefs may be contradictory, differing even for a particular individual according to professional and personal personas. Hence, policymaking is rarely or never based around full and fully-evidenced certainty, and is subject to institutional perspectives which reflect those organisations’ wider missions and objectives, and indeed coalitions of such perspectives.

From this theoretical perspective, as we develop later, the emergence of greater automation and connectivity in the road transport sector – and with the prospect of this further intensifying – can be characterised as one in which the construction of knowledge is particularly open to interpretation. It is particularly open due to the importance of technical information to the policy questions, limited evidence, and long development timelines. Herein, the 'stakes', both financial and authoritative, that institutions have in particular policy outcomes are high. Aspects of automation and connectivity offer an enticing prospect of being able to fulfil several long-standing objectives of transport policy that have been long-pursued yet not (fully) achieved by infrastructural and behavioural policy measures: safe and efficient mobility that is accessible to all. However, deep uncertainty and a paucity of hard empirical insight regarding innovation delivery and diffusion in relation to CAVs makes evidence-led policy difficult if not impossible.

While the language of revolution is used by many commentators to depict the impact of CAVs on the transport system, this can create a false impression of the rapidity with which transition to a brave new world will take place. Any transition will certainly defy the short timescales of electoral cycles beyond which policymaking in the democratic system struggles to engage. The *evolution* of capabilities and adoption of those capabilities over a period of - perhaps - fifty years seems a more credible prospect. In short, the promise of these technologies on the one hand and limited challenge to attractive but fleet-of-foot visions on the other has resulted in what can be identified as an emotive enthusiasm for the CAV.

We review some of the motivations for policy enthusiasm in the remainder of this section. The following section then turns to consider the key assumptions underlying CAV (en)visioning. We then give further attention to what we suggest is a neglected yet quite profound assumption relating to CAV futures, namely that strangers will share small driverless vehicles in a mobility ecosystem defined by access to, rather than ownership of, vehicles.

2.1 The Economic Imperative

The last decade has been one of economic austerity affecting most economies worldwide. Political demands for a return to 'normal' conditions of economic growth have seen other policy objectives reduced in priority. At the same time there has been a resurgence of national economic priorities as a challenge to neoliberal policies promoting global free trade and economic integration. US policy under President Trump to leave the Paris Accord on Climate Change and introduce new trade tariffs on certain metals, justified as necessary protection for both American prosperity and jobs (indeed 'national security'), is the highest profile exemplar. In this context, the assumed benefits that lie behind capitalising on the promotion of CAVs as an economic activity are perhaps sufficient motivation in themselves. This appears reflective of what Merton would have called 'imperious immediacy of interest' (Merton, 1936) – an underlying cause of unanticipated consequences.

The UK Department for Transport, in the forward to a document setting out proposed policy support measures for CAV development, foresaw the technologies as having the potential to "*lead improved productivity, and increased trade as British industries capture part of a wider global market for Intelligent Mobility*" (DfT, 2016: 6). The document continued in quoting an assessment by the UK QUANGO the Transport Systems Catapult (2015) that this market might be worth £900bn[iv] per annum by 2025. However, this economic activity needs to be seen in a broader context of possible economic opportunity costs if significant public sector resource is invested in CAV industries. Other economic costs, such as reductions in employment due to automation, and the wider social and environmental consequences of this pathway of economic development need recognising.

The economic imperative has been further fuelled by a sense of 'winner takes all', or at least 'grabbing a share of the pie' in a global race to realise the economic potential of CAVs. Governments appear enthusiastic to be facilitators of advancement in terms of addressing regulatory matters and enabling test environments to become a proving ground for the CAV technology. A key concern here is the extent to which the economic imperative may be giving greater priority to *facilitating* the arrival of CAVs as opposed to setting appropriate framework conditions to help ensure and *shape* responsible innovation, i.e. realising and locking in the benefits that CAVs may be able to offer (in the fulfilment of a wider set of policy goals) while guarding against rebound effects and unanticipated and undesirable consequences.

2.2 CAVs and Future Mobility

In addition to the economic output benefits which might derive from developing a new high-tech manufacturing and services sector around CAVs, a second potential major source of economic benefits is predicted to arise within the transport sector itself, due to more efficient resource allocation.

From the sociological institutionalist perspective, it is of no surprise that the enthusiasm shown by many policymakers for CAVs has been matched amongst the professionals networked with them in both the private and public sectors, and not limited to the transport sector. The *potential* benefits that have been attributed to CAVs - *but which are also contestable* - include:

- Transport system safety - near elimination of vehicle collisions, with associated wellbeing benefits, transport system benefits, and reduced health system costs (Fagnant & Kockelman, 2015). *This in part presupposes the technology becomes fail-safe (including resilience to software hacking). While road traffic accidents and fatalities may be substantially reduced, CAVs could perpetuate sedentary lifestyles with adverse consequences for public health including lost years of life.*
- Transport system efficiency - greater effective road capacity (through reduced vehicle headways and/or increased throughput of people movement due to higher vehicle occupancies) and smoothed traffic flow (Fagnant & Kockelman, 2015). *If fully autonomous vehicles are hailed, not shared, and run empty between picking up passengers, a downwards pressure on efficiency could result – thus the model of CAV usage is key in determining efficiency.*

- Social inclusion – enhancement of mobility for those unable to drive themselves because either they are not qualified to do so or have impairments preventing them from doing so (e.g. DfT, 2015); and greater social cohesion is also possible through increased human interaction as a result of (synchronous) shared use of vehicles. *Mobility enhancement presupposes fully autonomous CAVs, and human interaction presupposes a culture of shared use.*
- Economic productivity - travel time use released from the manual driving task able to be repurposed for other (potentially economically productive) activities in the vehicle (Steck et al., 2018). *Ride quality and motion sickness are factors that could significantly govern how travel time is used; productivity gain is relative to existing productivity of car drivers who are already able to multitask (the driving task alongside other activity) in relation to time uses such as thinking, talking and listening.*
- Placemaking - a built environment renaissance for streets no longer oriented around the car and roads (including highways), with excess movement (and vehicle parking) space deriving from transport system efficiency able to be repurposed (e.g. Skinner & Bidwell, 2016). *If efficiency deteriorates due to the model of CAV usage that emerges, pressure for movement space could increase, compromising prospects for enhanced placemaking.*
- Environmental quality - reduced energy use, climate change emissions, and noxious emissions affecting local air quality driving from improved transport system efficiency (Anderson et al., 2016). *This presupposes an efficiency gain.*
- Monetary cost of mobility - modest increase in vehicle purchase costs (once production fully commercialised), but use costs reduced either for users or fleet operators (Fagnant & Kockelman, 2015) – *though this presupposes a favourable model of CAV usage, notable from the end user perspective*.

Such benefits, since as yet unrealised, are founded upon a number of assumptions. Notwithstanding the veracity of these assumptions, attempts exist to quantify prospective benefits. Fagnant and Kockelman (2015) have perhaps gone furthest in making the positive case for automation, in undertaking a cost-benefit analysis of the classic transport-sector factors (mainly reduced collision and congestion costs). In their highest market-penetration scenario (90%), and with assumptions about traffic generation and vehicle sharing, the net direct economic benefits were calculated to reach $196 bn per annum for the US, and as much as $442 bn if associated indirect benefits were included. Notably, this estimate for the US fits within the global estimate (for benefits only) by Manyika et al. (2013) (a team from McKinsey's Global Institute). This identified potential impacts of $0.2-1.9 trillion by 2025, although based on a much lower level of take-up (5-20%, allowing for differential take-up around the world). Unlike Fagnant and Kockelman, Manyika et al considered semi-autonomous as well as fully autonomous driving, and included in-vehicle benefits due to drivers being released from the driving task. Arbib, and Seba (2017) estimate productivity gains from travel time use alone could be $1 trillion by 2030. This estimate derives from a remarkable set of assumptions involving system dynamics leading to a transformation of the mobility system towards one that is predominantly connected, electric, fully-autonomous and functioning through Mobility as a Service (MaaS) by 2030.

These studies confirm that reasoned assumptions applied to possible adoption scenarios are capable of generating very significant implied economic benefits both within the transport sector and beyond it[v]. Whilst assumptions may be clearly identified and caveats carefully attached, such high profile findings can take on an influential life of their own, once the original report is summarised and the headline figure extracted from substantiating context. It is therefore important to interrogate the assumptions and be reminded about the important qualifiers.

3 KEY ASSUMPTIONS OF CAV SCENARIOS

Language matters in futures analysis and can be the cause of significant confusion or ambiguity if care is not taken. A scenario is a "postulated sequence or development of events"[vi]. There are predicted, presumed, practical, plausible and preferred scenarios (see Lyons and Davidson, 2016). A practical scenario is one that suits imperatives of the immediate future. Preferred scenarios are value laden and depict future states that are desirable. The term 'vision' can be synonymous with 'scenario' but tends towards a connotation of preferred scenario. Predicted and presumed scenarios carry the connotation of limited uncertainty and some implied degree of confidence in the scenarios coming to pass. A plausible scenario (commonly part of a set of such scenarios when developed as part of a scenario planning approach (e.g. Milakis et al, 2017) is one that acknowledges (deep) uncertainty and, in light of such uncertainty, could come about. All scenarios involve assumptions. The future prospects for CAVs, many argue, are subject to deep uncertainty and therefore any portrayal of a CAV scenario and its consequences will be heavily founded upon the (contestable) assumptions (implicit or explicit) made. We suggest there are four categories of important assumptions concerning CAV scenarios:

1. Technology - assumptions about whether or when and to what extent technological barriers to fully autonomous vehicles will be overcome.
2. Adoption - assumptions about how far, how fast and why CAVs will penetrate into the vehicle fleet (in the hands of either fleet or individual owners).
3. Performance - assumptions about how the adoption of the technology will play out and assumptions about the consequences.
4. Synergies - assumptions about whether, to what extent and how transport and society beyond CAVs themselves will change and how this influences CAV supply and demand.

Figure 1 is a simplified illustration of how what we refer to as *assumption pathways* underlie any articulation of a future CAV scenario[vii]. The arrows depict assumptions. These go into any taken position on technology readiness. This then feeds forward with assumptions going into any taken position on nature, extent and pace of adoption. This in turn feeds forward with assumptions going into any taken position on the performance features and consequences of adoption. Assumptions regarding synergies between CAV development and wider transport and society underpin assumptions along the technology-adoption-performance pathway. The large arrow depicts the cumulative set of assumptions along the pathway leading to any depiction of a CAV scenario. Symbolically this arrow is a reminder of the extent of assumption in the face of deep uncertainty.

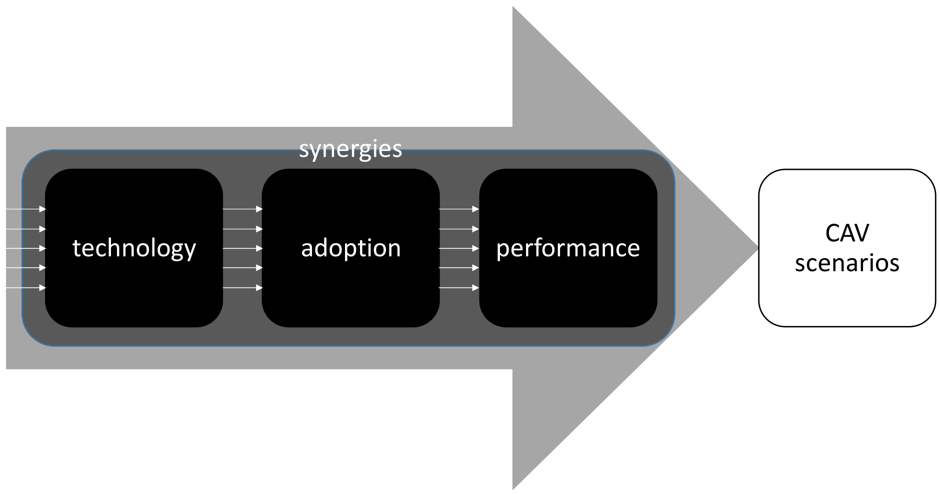

Figure 1. Assumption pathways towards future CAV scenarios

3.1 Assumptions about Technology

The rate of technological development is perhaps the most important of these assumptions to the political process. Likely developments are viewed from the perspective of the temporality of political cycles, in terms of policy review, elections, and, in the democratic system, whether claims, targets, and promises will be verifiable within the likely timescales of a government mandate or a political career. The policymaker seeking to make time-related assumptions is faced on the one hand with what are, without doubt, impressive accomplishments, notably the many millions of kilometres of operation of the US Google/Waymo fleet on public roads with relatively little human input over several years. On the other hand there is a growing list of fatal crashes and collisions. Together these lead to debates about whether the machine failure rate is greater or lesser than the equivalent human one might have been in the same set of circumstances. There is an important (and potentially emotive) moral debate about whether machines and humans can be compared in this way, and whether any level of machine error is acceptable. For the purposes of this paper, the key point is that the observer is forced to take a view on conflicting evidence regarding these failures: are they inevitable learning experiences on the way to eventual success; or confirmation that the ambitions of full anytime, anyplace, any condition automation are unrealisable? Kalra and Groves (2017) compare earlier introduction of CAV technology onto our roads with the opportunity to learn from mistakes (including fatal accidents) and save more lives in the longer term, versus later introduction where delay could cost more lives being lost to the world of manual driving in the interim.

Technology readiness in the discourse of forecasts faces ambiguity regarding the specific meaning of automation being applied. Definitions such as the SAE levels of automation[viii] in principle can help clarify. Yet they can be complex to explain to all actors and stakeholders, to the point that they are not realistically deployable in public debate intended to be inclusive. The levels themselves, or rather the definition of specific performances against the defined levels, are somewhat ambiguous, meriting further qualification. For example references are now being made to 'level two-and-a-half' automation, for a vehicle which has the capability to operate in specific circumstances without a human in contact with the controls, but indeed, so specifically that there will be frequently-arising events beyond system capability, such that manufacturer's advice and legal regulation require continuous human contact. The existence of such ambiguities creates opportunities for miscommunication and misplaced optimism amongst policymakers, or even 'hype' – which in principle might be unintended or arise through negligence – about current, as well as the timing of future, capabilities.

Less often recognised in the debate over technology readiness is also the important contingency between: (i) the views taken by policymakers about the realistic technology development trajectory (informed by technologists whose natural tendency is to present their achievements in the most positive way possible); and (ii) the willingness of the legislature to accept that change is coming, and therefore the need to invest political capital and executive (i.e. civil service) resource in bringing about the changes to national laws and road traffic regulations (e.g. covering driver behaviour and insurance requirements), required to make the technology viable in practice, not just in the laboratory or on the test track. Significant investment in CAVs is being undertaken by the private sector. There is public sector funding too of direct CAV development. While significant in terms of public R&D spend, this is relatively small compared to automotive sector investment. Hence, likely high on the private sector 'risk registers' is that the regulatory context will not be sufficiently benign, resulting in pressure on the legislature. From the industry perspective, the role of the state is perhaps measured not so much in terms of monetary investment, but the willingness, indeed enthusiasm, it has for pro-CAV regulatory change (see CSPC (2017)) and, less tangibly, in providing official sanction to what may (or may not) amount to a cross-sectoral revolution.

Assumptions regarding technology extend further to consider whether or not, and how, door-to-door transport system infrastructure itself would need to adapt to accommodate or facilitate market-ready vehicle technology.

3.2 Assumptions about Adoption

Political enthusiasm, advocacy from technologists, and media hype can portray a sense of inevitability for citizens themselves: 'a CAV future is coming'. The policy 'frame', or selection of salient information to construct a compelling narrative (Schön and Rein, 1994) can influence future public acceptance. Yet this alone will not govern citizen buy-in to, and adoption and use of, CAV technology. Ultimately, technological acceptance depends upon a range of factors such as: the perceived utility of the new product or service compared with existing ones being used by consumers; and more psychological factors such as the value of brand and the perceived connectivity between product or service and lifestyle. Becker and Axhausen (2017) reviewed surveys of public opinion on CAV acceptance to date. Where such studies have measured general favourability towards the technology or willingness to use, they have tended to identify small majorities or large minorities in favour, rather than a dominating view. Becker and Axhausen leave this point implicit, although do identify that youth, urban context, ownership experience with advanced driver assistance systems and those well informed about technology tended to be most positive. Less is known about the basis of resistance to CAV technology, but safety is a factor which can influence both negative and positive attitudes, depending on whether the observer believes human or automated systems to be safer (Clayton et al., n.d.). It is likely that more general reticence towards the unknown and unfamiliar is also a factor. It may also represent a more fundamental attachment to the status quo.

Such uncertainty concerning adoption, and in turn any rate of diffusion of CAV innovation, is not explicitly recognised in the policy discourse. It is, however, implicit in the policy rhetoric around the need to 'understand user acceptance', a formulation of words that seems to suggest that all citizens will become users if we can only unlock the secrets as to what will make the technology acceptable. In other words, interest is in how to secure acceptance as distinct from whether or not citizens consider CAVs to be a welcome addition to our mobility future. The latter is taken to be a priori by CAV proponents.

The late John Urry articulated succinctly a prospect for resistance to acceptance, suggesting that presumptions to the contrary "ignore just the pleasures of driving, of finding your way, and, especially for many male drivers, for driving too fast and aggressively" (Urry, 2013). Urry makes his own assumptions here: that users will have a passive role in navigation; and that automated driving styles will be slower and calmer than human driving styles. However, his quote serves to emphasise that decades of 'automobility' have resulted in major social, economic and cultural attachment to the car, and resistance to CAVs may be greater than the mainstream discourse accepts.

A further key perspective which has not hitherto had significant discussion in the transport sector, although is increasingly recognised in the social policy domain, is that automation is a cross-sectoral development – public acceptance or otherwise of which has a bearing upon CAV adoption prospects. McKinsey (2017) identified that 60% of occupations have at least 30% of constituent activities that could be automated based on existing technologies. Considering future likely technological development, Lawrence et al. (2017) concluded (with a probability of 0.7) that the penetration of automation will range from 23-65% depending on sector. If it does indeed transpire that there is far less work to go around, then a new social-fiscal contract will be necessary to avoid politically unsustainable disparities in income. Risks therefore relate to whether (and when) such a contract is forthcoming, and whether it is effective. Significantly greater income disparities might influence the mode of adoption of CAVs. More fundamentally, there might be a political backlash against automation, echoing the late-18th Century Luddite movement against mechanisation in the textile sector. However, a cross-sectoral reduction in the need for unskilled and semi-skilled labour, combined with a modest rise in skilled and professional labour, might amount to a major net reduction in employment opportunities. In the absence of at 21st Century 'New Deal', social strife seems an outcome that should feature prominently in scenarios.

3.3 Assumptions about Performance

Performance assumptions concern how it is envisaged that adoption and use of CAVs will affect how the transport system operates and what benefits (or disbenefits) flow from this (as outlined already in Section 2.2). We do not elaborate upon all the areas of performance and benefit that have been identified in promotional CAV discourse, but consider below a selection of these, in order to highlight just how many questions and, by implication, assumptions arise.

Will travellers demand similar-to-current performance from AV road transportation or will priorities change? Will the imperative of speed and improved journey time endure both for individuals and their travel choices and for the business case for ongoing investment in the transport system? Conversely, will this imperative be diminished if other in-CAV activities are possible while on the move? How realistic is it that CAV ride quality will (fully) enable such repurposing of travel time for productive use? New active suspension technologies may assist, but could ride quality trade-off with vehicle throughput in the transport network? In order to achieve rail-like standards of comfort and passenger experience, speeds through network features such as signalised intersections might need to be reduced, thereby affecting network efficiency and any assumed benefits from this (Le Vine, Zolfaghari & Polak, 2015). Will vehicle occupants be required to be alert for some or all of the time while in a CAV and with what implications for the sorts of activities they might engage with to occupy their travel time and with what consequences for productivity?

How will CAVs operate as vehicles in terms of both movement and being stationary? Will a CAV be used in a way similar to a manually-driven private car, whereby it is parked at the destination before its user requires the onward or return journey to be made? Will it drop off its occupant and go to a remote location to park until required by its user? Might it circulate or be repurposed for use by other individuals until the (primary) user requires it again for his or her own onward or return journey? How will parking provision itself be (re)designed on the basis of CAV self-parking functionality and possibilities to reduce the need for space adjacent to the vehicle for opening doors to gain access? How will environments – notably urban – be designed and with what rules to govern interactions between CAVs of different sorts and between CAVs and manually operated vehicles and pedestrians? There are many such questions at different levels of specificity that require answers or which have implied answers in the course of an assumption pathway towards a CAV scenario.

The estimation of benefits in relation to CAV development may (as in other aspects of transport appraisal) be hard to quantify. As Wadud, MacKenzie and Leiby (2016) emphasise, though, their outturn values remain critical: *"automation might plausibly reduce road transport GHG emissions and energy use by nearly half – or nearly double them – depending on which effects come to dominate"* (*Op. cit.*: 1).

Moreover, it is not sufficient to consider only first order rather than second and third-order indirect effects of CAV development. An example of this is the assumption that fully-autonomous CAVs promote inclusion by giving access to vehicles for those unable or unwilling to drive themselves. While this may promote individual mobility and access, this could have indirect longer term effects that run counter to a more inclusive society. Kenyon et al. (2002) have pointed to the potential irony that pursuit of greater inclusion for individuals in society through enhancing their access to mobility can lead to a more exclusive society overall where dependence upon (individualised) mobility and dispersal of land use patterns contribute to greater financial, social and health-related costs for the individual in being able to meet their goals.

3.4 Assumptions about Synergies

It can be a significant shortcoming in speculating about future prospects of a given innovation to overlook or underestimate the importance of how the context within which the innovation is to play out will itself have changed, and in what respects. At the extreme, a CAV scenario could assume that beyond vehicle control shifting from the human to the machine, all else remains the same – i.e. that there is no other social, technological, economic, environmental and political change that would otherwise impact upon people's needs, desires and behaviours. In practice society is subject to innovations, developments and changes in practices across sectors that have intra- and inter-sector consequences and dependencies. The number of such potential synergies that could have consequences for the veracity of CAV scenarios is considerable, underlining the deep uncertainty with which any forward projection of CAV prospects must contend. In this section we consider two such synergies by way of illustration.

Electrification of the road vehicle fleet

After many years as a marginalised technology, electric vehicles are now receiving strong policy support in many states. Electric vehicles are subject to their own set of adoption and acceptance barriers, although a schedule for fleet replacement by electric and partially electric (hybrid) vehicles is now clarifying. According to jurisdiction, full internal combustion engine (ICE) vehicle sales will be ended in the medium-term future (in the case of the UK, by 2040). Depending on how 'residual' ICE sales have become by then, a further period of up to 15 years might be necessary for vehicles (other than those of ongoing historic interest) to exit the vehicle fleet. These timescales are not out of step with some of the medium-speed forecasts for the CAV transition.

Most prototype CAVs have indeed been powered by battery-electric or hybrid systems. CAVs can be expected to place higher demands on vehicle electric systems than human-driven vehicles, although the additional consumption may fall in importance with further battery improvements and energy efficiency gains. Little discussion has been had about whether there are any more important positive and negative feedbacks between the two transitions. One emerging sub-synergy relates to the significant constraints on providing charging capacity on a commercial basis for premises without off-street parking. Existing street power supplies (e.g. to lampposts) are limited in their coverage. Solutions using cables to individual vehicles must overcome public safety (e.g. trip hazard) concerns. Once a vehicle is connected to a charging facility, and in the absence of incentives to move it once charged (and these may not be realistic in residential streets), the charged vehicle may block access to other vehicles in need of charging. In principle, full automation of both vehicles and charging points could enable charged vehicles to be relocated once charged to enable efficient and maximum use of the charging infrastructure.

Sharing

One of the most significant synergies for CAVs – yet one we believe is thus far underestimated in terms of its importance and uncertainty - to emerge from the literature is the *real* potential for sharing. Fagnant & Kockelman (2015) assumed (based on the outputs of a feasibility model that showed the outcome to be possible) that 10% of AVs would be shared (use, not just ownership), although recognised this assumption was sensitive to factors such as average trip length and density. Similarly, for typical European city conditions, the International Transport Forum (ITF) (2015) showed, through scenario modelling, that in principle a synchronously-shared CAV fleet would require only 10% of the number of current vehicles to provide for existing mobility, whereas an exclusively-used collective fleet would still require 77% of current vehicles to be retained. Overall traffic and peak congestion increases in the ridesharing option would be modest (6 and 9% respectively). Exclusive use would effectively double both measures, regarded by the ITF as an unmanageable outcome.

However, such findings are now widely cited to support scenarios for 'future mobility', without much attention paid to two basic questions:

- What form of vehicle sharing is being proposed: synchronous or asynchronous?
- What evidence is there that either of these modalities of sharing is likely, at any significant scale?

The following section elaborates on this.

4 SELF-DRIVING CARS: IS ANYONE IN THE *PASSENGER* SEAT?

Currie (2018) offers a damning indictment of mainstream evangelism and promotion of CAV futures and in particular the portrayal of sharing as a notable feature. He refers to "the unscrupulous use of the word *sharing* by technologists to imply that new mobility modes [including CAVs] are good" (Currie, 2018: 22). His concern relates to the implication that by associating CAVs with sharing this helps to position them favourably against the traditionally shared modes of public transport. He points to evidence of car occupancies in practice declining as opposed to increasing. This suggests that sharing is not as self-evidently a phenomenon that is set to (naturally) grow as part of the new mobility agenda as other commentaries on CAV futures state or imply.

Such critique shines a light on our two questions above, highlighting that shared use synchronously (ride sharing) and/or asynchronously (a shared vehicle service individually used) is not a given but remains an assumption regarding any CAV scenario. However, to reject the plausibility that vehicle sharing will not be a feature of CAV futures would be to deny the uncertainty over future behaviour.

Some transport service attributes of CAVs do indeed suggest specific utilities that could influence traveller decision-making in favour of shared vehicles. Considering first the automation aspect of CAVs, self-driving technology offers to radically reduce transport service operating costs by eliminating much of the labour costs. Expectations that automated driving will be optimised suggest lower insurance, energy and maintenance costs. Lower operating costs are likely to result in much lower fares, reducing the relative attractiveness of owning a private vehicle. Assumptions concerning sharing would then also need to account for the types of vehicles (in terms of carrying capacity) that would populate future mobility fleets in CAV scenarios – ranging from small pods across to autonomous buses.

Connectivity will contribute to operating efficiency through the sharing of information about strategic conditions on the network and, at the tactical level, the intended movements of other vehicles. However, connectivity also enables very precise information about vehicle location and state of occupancy, and enables the effective operation of a dynamically-routed service. Again, this suggests the relative attractiveness of collectively-available transport services could increase relative to owning a private vehicle.

However, these transport service attributes only directly influence the attractiveness of a vehicle which is not personally owned. At level 5, the 'driver persona' may weaken considerably and be a reduced source of attachment to the car. However, symbolic and emotional attachment to the car is a longstanding characteristic of the automobility regime. Confidence in this being overturned in future CAV scenarios would seem misplaced.

The influences on willingness to synchronously share are more subtle, and bidirectional. Connectivity would enable greater in-vehicle surveillance, and, subject to privacy constraints, might potentially provide information about other passengers using the vehicle, or intending to join it. However, automation, whilst enabling a step-change in operating costs, does so by removing the presence of a person with authority over the space, relocating that authority to a control room, potentially miles away. This would likely be unable to monitor the minutiae of every behaviour in every vehicle present on a network simultaneously. A remote operative might avoid much potential crime emerging. Yet, there might be limited impact on the social environment of the cabin, leaving transgressions of behavioural norms short of criminal activity (*e.g.* unwanted interaction, offensive language and invasion of personal space) unchallenged.

Hence, there are significant social psychological barriers to sharing vehicles with others (Merat et al., 2017) and insufficient discussion exists to date about whether these fundamentals are likely to change, before the leap of policy faith is made to envisaging a collective mobility future for CAVs.

5 CONCLUSION

In this paper we have sought to get behind the positive expectations surrounding the prospect of a CAV-oriented mobility revolution in society. We have given prominence (see Figure 1) to the multiple categories of inter-related assumptions that are necessarily made (explicitly or implicitly) when envisioning future scenarios for CAVs in the face of a deeply uncertain future. Such assumptions can be likened to the creation of a house of cards. The lower down (or more fundamental) the assumptions are in the house, the more likely the house is to fall down if these are incorrect.

The observed importance of the motor car to post-war economies in the second half of the 20th Century suggests that with strong policy support the CAV could serve the same role as the family saloon of the 1960s and 1970s; as a key economic consumer product of the early 21st Century. However, given the social and environmental objectives of transport policy, the economy should surely not be an overriding justification to promote CAVs, come what may. Indeed, even if an economic imperative prevails, it seems far from clear in our examination in this paper that CAVs guarantee being able to realise the eye-watering economic benefits suggested by some commentators that, it might be suggested, have seduced some policymakers. Transport policy support for CAVs should be conditional upon CAVs making a genuine contribution to sustainable mobility – sustainable economically, socially and environmentally. This leads to a need to recognise the important distinction made earlier in this paper between enabling versus shaping the nature of any future mobility paradigm inhabited by CAVs. These are not mutually exclusive but the latter must feature strongly.

To this end, current models of CAV adoption are, for the most part, insufficiently developed. There is insufficient attention given to systems thinking that accounts for all important potential feedback loops. While sharing is not the only territory of assumptions that underpin envisioning CAV scenarios, we consider it may be one of the more fundamental and fallible assumptions of current positive discourse and outlook. We can see no apparent and compelling reason why synchronous sharing would evolve at a scale to significantly influence the business model of CAV adoption - unless government intervenes using traditional transport tools (prices, regulations), to favour synchronous sharing. In some respects this is just the same old transport problem but at higher stakes: without it the basis of a positive, sustainable mobility vision for CAV adoption falls.

Public and private sector players will exert influence over shaping future mobility and in this sense are in the driving seat. Yet the transport system users, in the choices they make within and beyond the transport system, are also a collective source of key influence – another driver of (or source of resistance to) change. Where we are heading is far from clear, not least because there may be no-one in the passenger seat.

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[i] The term 'automated' is emerging as a more accurate description of vehicles which are predicted to cooperate (rather than make decisions entirely autonomously) in road networks, but we adopt here the term which has been the convention in the debate hitherto.
[ii] Venturer http://www.venturer-cars.com/, Flourish http://www.flourishmobility.com/, CAPRI http://caprimobility.com/. Specific project findings drawn upon are referenced. In addition Graham Parkhurst is grateful for the formative influence the debate within these consortia has had.
[iii] Unpublished, led by Kantor Public. Broad experiences from the work inform, but no specific data are used, in the current paper.
[iv] A figure whose provenance is not readily apparent.
[v] Manyika et al. identified CAVs only as sixth in rank order magnitude of benefits out of twelve "disruptive technologies", with a significant step down from the fifth-ranked 'advanced robotics' to CAVs.
[vi] https://en.oxforddictionaries.com/definition/scenario
[vii] In practice such a pathway would not be purely linear in nature with, instead, feedback loops within and between elements and their assumptions over time.
[viii] https://www.sae.org/standards/content/j3016_201609/