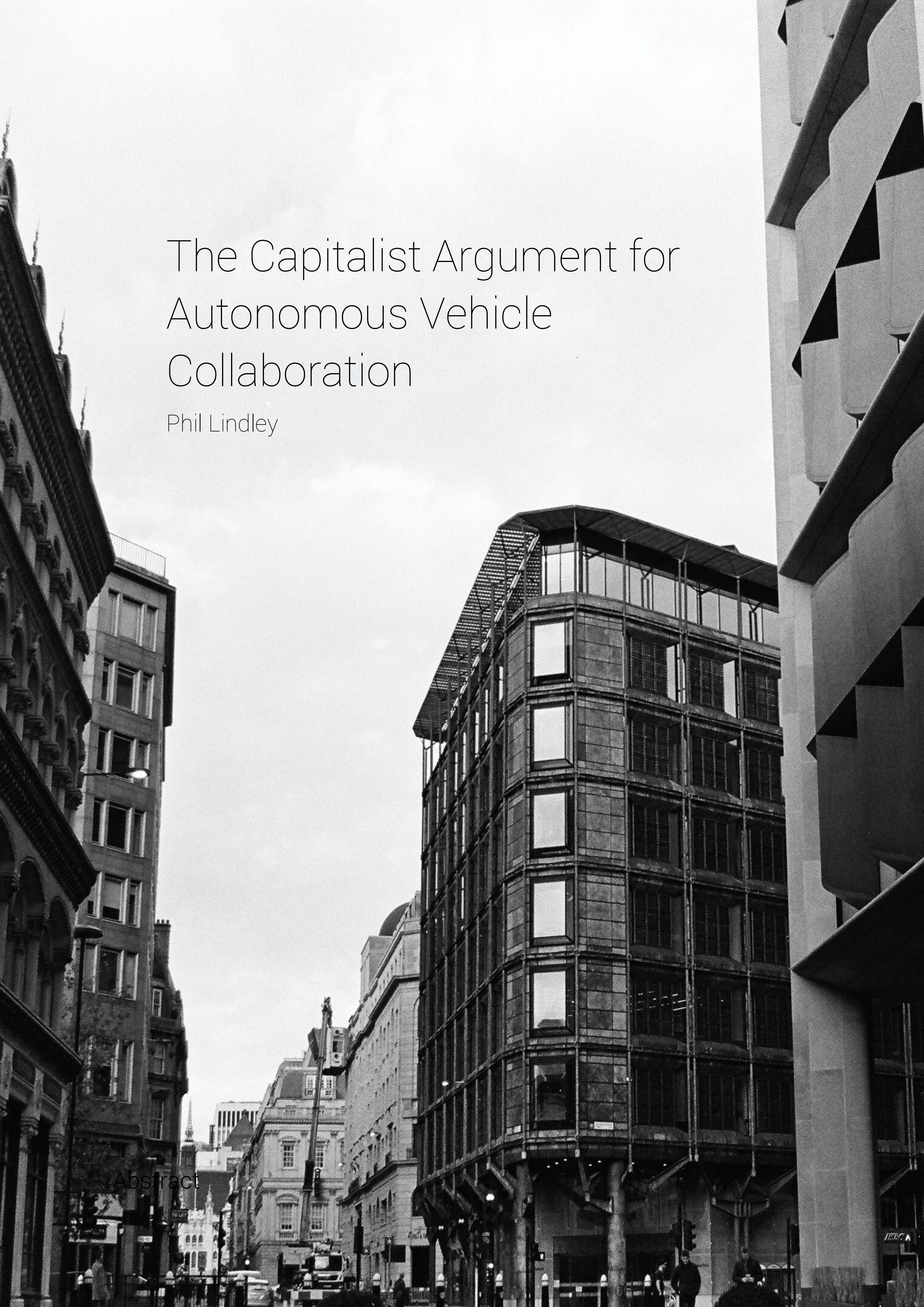
The Capitalist Argument for Autonomous Vehicle Collaboration

Phil Lindley



Abstract

This paper seeks to explore the current trajectory for the rollout of Autonomous Vehicles and their supporting technologies. This involves evaluating their history, analysing the current state of play from relevant literature and then forming this into a thesis for further exploration.

Academic and Industry sources are queried to affirm direction and further gather secondary resources. These are then compiled and evaluated to form a clear problem statement around the lack of a defined path for the rollout of Autonomous Vehicles. Alongside this, it was found that there is a lack of literature around how the promised safety benefits are to be realised without a definite vision and industry collaboration to enable vehicle to everything communications.

It was identified from this that there is a need for a pivot within the industry towards focusing on an integrated city-first directive to maximise profitability, adoption and societal benefits to be gained from Autonomous Vehicles. A proposition was formed for achieving this via the use of a simulated environment coupled with the definition of open-source standards to enable collaboration and simplify regulation within the industry, with an end goal of accelerating the transition toward connected smart cities with efficient and environmentally sustainable transport networks.

Acknowledgements

Firstly, I would like to thank my dissertation tutor Rob Stephens for his guidance throughout the process.

In addition, I would like to thank all of those who took part in my primary research for industry insights, the conversations, observations and resources provided proved fruitful and helped me further develop my ideas.

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Finally, thanks to my friends and family who have provided consistent support and inspiration especially during this final year.

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Abbreviations

ADAS – Advanced Driver Assistance System

AV – Autonomous Vehicle

BAU – Business as Usual

CAV – Connected Autonomous Vehicle

IoT – Internet of Things

IP – Intellectual Property

L4 – SAE Autonomy Level 4

L5 – SAE Autonomy Level 5

MaaS – Mobility as a Service

NHTSA – National Highway Traffic Safety Administration

OTA – Over the Air

SAE – Society of Automotive Engineers

USP – Unique Selling Point

V2I – Vehicle to Infrastructure

V2V – Vehicle to Vehicle

V2X – Vehicle to Everything

Definitions

Big Auto – Major automotive companies such as Volkswagen with inordinate influence

Big Tech – Major technology companies such as Google with inordinate influence

Capitalism – The current prevailing economic system which entails a free market economy where capital is held privately, and goods and services are delivered via competition

Catch 22 – A dilemma from which there is no escape due to a mutually conflicting solution

Free Market – An economy where price is determined by competition between private entities

Full Stack – A complete software/hardware package to enable autonomous driving

Level X – Defined within this paper as any Vehicle/Infrastructure compatible with V2X

Moonshot – A Google term to describe pursuits in a similar grandeur to the moon landings

Neoliberalism – A movement towards free market trade, deregulation and individualisation

Smart Cities – A city enriched with the IoT enabling integration and connectivity

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1. Introduction

1.1 Dissertation Overview

This dissertation will investigate the present state of Autonomous Vehicles (AV's) and their current trajectory towards mass-user adoption. Following this will be an exploration of the potential for convergence between disruptive technologies such as 5G, Blockchain, IoT and Smart City's which together are nearing maturity producing one of the most significant opportunities for evolution in mobility since the mass adoption of Fords' Model T.

By drawing on current literature surrounding the topic, a problem statement will be formed, followed by exploring the opportunities to rectify any issues identified.

These findings will then be synthesised into a working proposal for the advancement of mobility and city transport utilising an information system comprised of the tight integration of various current and emerging technologies supporting greater industry collaboration.

1.2 Aims and Objectives

The overarching aim of this dissertation is to highlight the omissions surrounding the current trajectory for the rollout of Autonomous Vehicles; exploring the general failings within the industry to harmonise. From this, potential opportunities will be explored and discussed further.

Objectives:

- Provide an introduction to the current state of AV's and surrounding technologies
- Articulate a problem statement from the current direction of adoption
- Counter the problem statement with a high-level proposal
- Articulate a theoretical business case to help steer towards the proposal
- Conclude by comparing the current vs. proposed rollout strategy

1.3 Chapter Structure

1. **Introduction**
A summary of the thesis for this dissertation, its aims and conduct.

2. **Autonomous Vehicles, where are we today?**
Demonstrating a holistic overview of the current state of play within the AV space exploring supporting developments and blockers, finalised with a summary of the thesis and industry insights.

3. **Autonomous Vehicles, further critiquing the current trajectory**
By analysing the strengths and weaknesses of the current trajectory within the AV space, a critical appraisal will be conducted to identify pain points and opportunities.

4. **Autonomous Vehicles, a new direction? 'the path to level X'**
Countering the problem statement articulated in the previous sections by identifying the key steps that need to be taken to correct and improve the path of AV adoption to maximise efficiency and societal benefit.

5. **How to achieve this? The 'Sim City' Proposition**
A practical proposition to accelerate and incubate the changes required for the path to level X at a greater pace than will be accomplished by the industry's current trajectory.

6. **Conclusion**
A closing summary of the elements discussed throughout this dissertation and final analysis with concluding thoughts.

1.4 Research Methodology

While exploring this topic, secondary research will be used, drawing on literature from academic or reputable business sources wherever possible. Due to the ever-present nature of the topic in hand, articles and news sources will be used throughout where academia is lagging. Wherever possible, peer-reviewed journals will be utilised, with accuracy and bias critiqued throughout as appropriate. When using business resources, there will be a preference for reputable consultancies and investment analysts. Articles and news sources will also be taken from reputable well-rooted outlets wherever possible. With regards to statistics used, as the majority of the information explored will be based on predictions of technology adoption, they may not all align, and some may even contradict. Such discrepancies are to be expected in such a developing topic area especially between different institutions publication dates. Any extremes in variance will be evaluated and critiqued in the body of the text.

Limited primary research will also be gathered to help verify the concepts explored, gather further resources and gain a consensus from both business and academic industry insights. This will help validate the initial investigation and affirm the base validity of any proposal concepts.

2. Autonomous Vehicles, where are we today?

2.1 A Brief History of Autonomous Vehicles

It all began in 2004 with a challenge presented by the US Military organisation DARPA (Defence Advanced Research Projects Agency). The premise was a competition open to the public to create an AV capable of covering a 142-mile course across desert terrain.

Out of the 15 vehicles taking part, 0 completed the race, with the greatest achievement being a distance of 7.31/142 miles (Spice, 2004). The prize was therefore unclaimed, and in turn, the competition ran again the following year under similar conditions, this time with four teams successfully completing the challenge (Orenstein, 2005).

In 2007, the challenge was relaunched, this time with urban driving being the centre of focus. The scenarios were within an urban environment with live obstacles and a requirement to conform to Californian road laws. This was the fundamental proof of concept behind the spur to make an urban AV a reality, resulting in many teams rushing to take part in the challenge and prove themselves within this crucial chapter in the inception of the technology (DARPA, 2014).

These competitions predominantly entered by University teams comprised of academics and engineers showed some, yet limited interest and sponsorship from the auto industry. The reason for this was in part as AV's are predominantly a software challenge rather than one of traditional automotive hardware; therefore, this did not appeal to the core competencies of big auto (Gao et al., 2016).

Interestingly, the 2nd place winners from Stanford University had the backing of Google's founders who were even present for the event. Core members of this team would later transition into becoming a part of Googles Autonomous Vehicle spin-off resulting in a subsidiary dedicated to the evolution of AV's, Waymo (DeBord, 2018).

Googles involvement was a show of things to come, as ten years later autonomous vehicle development is being dominated by big tech with Google being joined by the likes of Uber, Lyft and Apple to name only a few. Traditional Automotive manufacturers have also begun to make the shift towards investing heavily in this space. However, the transition has proven more challenging compared to their Silicon Valley counterparts predominantly due to a need to reconfigure their core competencies from embedded systems with a limited scope of upgradability/intervention to full stack software/hardware solutions supplemented with lifetime OTA (over the air) updates (Helbig, Schiller & Proff, 2017).

Throughout this text AV's will be referenced to predefined levels which range from 0-5 created by SAE and NHTSA, meaning they have quickly become an industry standard (SAE, 2018). Most tech companies such as Uber and Waymo are aiming directly for level 4/5 vehicles whereas the general direction of legacy OEM's is to go incrementally through levels 1-3 as the approach is more in line with their competence at incremental improvements alongside progressive shifts in regulatory and safety standards.

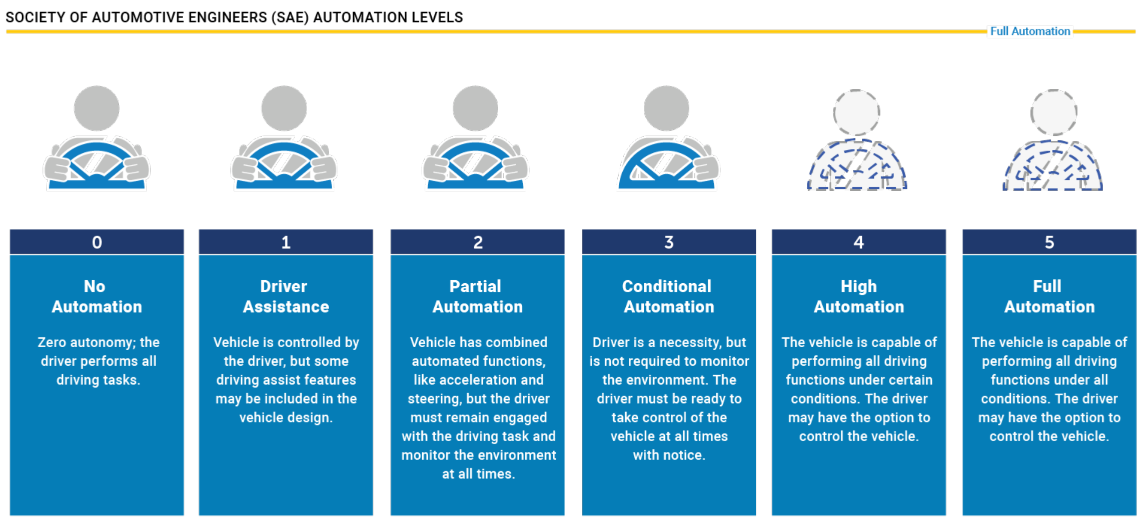


Figure 1 SAE Automation Levels (NHTSA, 2017)

The most significant promise AV’s bring into scope other than being a great technological milestone are mainly toted around prospective safety benefits supplemented with the potential to improve asset utilisation of both vehicles and transport infrastructure significantly. This is evidenced on Waymo’s homepage (Waymo, 2019), highlighting safety statistics such as:

- 1.3 million deaths worldwide due to vehicle crashes in 2016
- 2.4 million injuries in 2015 due to vehicle crashes
- 2/3 people will be involved in a drunk driving crash in their lifetime.

Alongside figures regarding access to mobility for new demographics and time savings:

- 3 million Americans over 40 are visually impaired
- 79% of seniors (65+) living in car-dependent communities
- 42 hours wasted in traffic by each person each year

While the above sounds rather promising, there is little information detailing a practical approach to resolve these issues, especially at the currently proposed scale. The increase in mobility will be definite; however, an actual reduction to congestion/deaths would be dependent on the approach and adoption of such technologies, alongside a high utilisation of new service models such as ridesharing and a general shift away from individual ownership. Without a societal change in situ with progressive adoption strategies some argue that AV’s could instead increase congestion due to the rise in access to mobility which may also lead to increasing individualistic transport, potentially at the detriment of highly efficient mass public transport.

New dilemma’s such as ‘ghost’ cars will also become apparent. Ghost cars are AV's without any occupants; these could be travelling between rides or even circling a block to avoid parking fees. Such issues will not be mitigated unless principles of sharing and efficiency are embedded into the core of solutions/regulation (Millard-Ball, 2019).

The grandest challenge at present in the AV sphere is commercialising the technologies into genuinely viable business models. Waymo has been struggling in this respect for a few years, with releases failing to deliver a truly autonomous experience. The current mobility service is limited to an ‘early rider’ programme which until recently was hidden behind NDA’s and still is consistently accompanied by safety drivers (Lee, 2019).

Continued supervision negates the key finical benefit of autonomous driving (which is already at an impasse due to the extremely high up-front vehicle and development cost) as maintaining any human driver/override raises costs and risks (Nunes, 2018). It also opens up the variable of human error, as was realised in one of Waymo's crashes within which the safety driver had fallen asleep (Griswold, 2019).

Although ahead currently, Waymo’s lead may be short as the majority of competitors both in tech and automotive are due to debut their L5 solutions in the next few years (Fagella, 2017), with Tesla recently stating ambitions to reach full L5 as soon as 2020 (Marshall, 2019).

Whether the laws will permit for these vehicles to be deployed however is another question (Kohler & Colbert-Taylor, 2015).

Previously safety regulations were introduced into vehicles extremely slowly (Eastman, 1984), partially due to cultural norms in the west promoting vehicle ownership and consumption at all cost, coupled tightly with massive lobbying directed by big auto with an agenda adverse to expensive safety regulation and audit (Wells & Nieuwenhuis, 2012).

It is for this reason that the NHTSA and similar bodies were initially formed to improve vehicle safety alongside defining common driving and infrastructure standards for vehicles (NHTSA, 2019). Over the last century, this has made driving and crashing significantly safer than it once was. However, it is still considered one of the most dangerous forms of transport (Naci, Chisholm & Baker, 2009).

This attitude will not be transferable to AV’s as the adoption of such a new technology coupled with shifting responsibility away from human control results in massive complexities including an innately emotional conflict with consumers. Especially within 'human' scenarios involving moral conflicts such as the much-debated trolley problem (Thomson, 1984). The crux of which essentially comes down to debating how morality is defined/programmed within AV’s, exploring whether, in the situation of an inevitable accident, they should protect the occupant at all costs, make a moral decision to focus on utilitarianism or something else that is yet to be defined.

Survey’s point towards general favour for the industry to build in utilitarianism, however on a personal level a preference towards individualism and the safety of the occupants is preferred, this is naturally a catch 22 for the manufacturer (Bonnefon, Shariff & Rahwan, 2016). To avoid such debates, coupled with the innately complex search for liability within AV’s systems (Marchant & Lindor, 2012), the need for the safety of solutions to be near perfection upon debut is essentially perceived by the public as a requirement (Koopman & Wagner, 2017), something which is arguably slowing Waymo and other competition down (Abuelsamid, 2018).

There are also arguments that AV's are already being given too much freedom, stating that tight standards, regulation and mandated testing needs to be passed before any more progress is made. Mary Cummings of Duke University Robotics testified to Congress stating that AV's were lacking "principled, evidence-based tests and evaluations" and a "clear certification process" which still holds true today (U.S Senate Committee, 2016). This sentiment can be seen reflected in the below diagram from Deloitte, demonstrating a consensus of fear around the safety of AV's at present, with a dependence on Government regulation and evidence of successful adoption required to overcome such anxieties by the public.

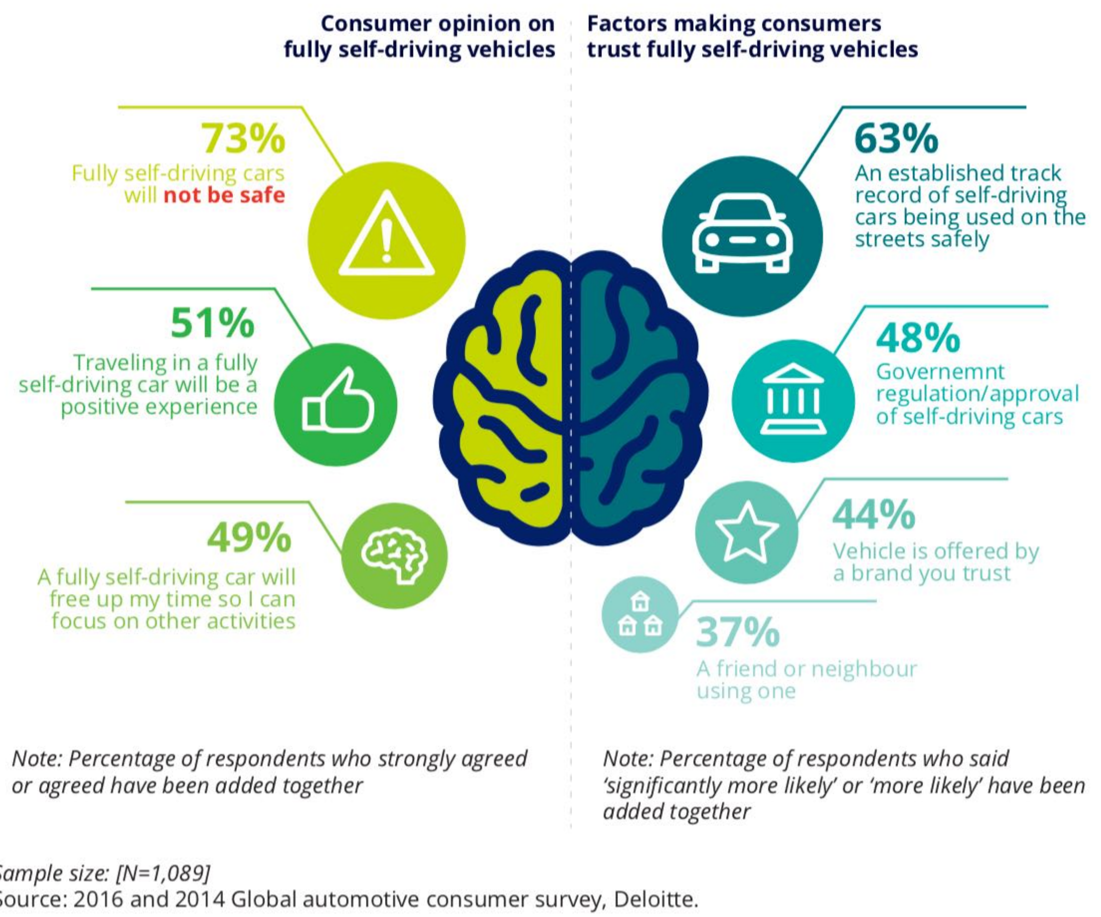


Figure 2 UK Consumer Views on Autonomous Vehicles (Bornstein, Rakow & Clemente, 2019)

While challenging to navigate, this kind of strict regulation is currently deployed within most embedded systems in cars, especially after a gradual, incremental transition to such standards taking place over nearly 80 years and thus resulting in extremely refined and generally well-governed safety, testing and recall procedures (NHTSA, 2012).

However, in the case of AV’s, due to the dependence on sophisticated software, which is often adaptive utilising aspects of neural networks, machine learning and even AI, the ability to accurately audit such technologies has been a debate in the spotlight for some time, with no clear defining answer as of yet (Koopman & Wagner, 2017).

It is also worth calling out the difference in the management of defects. When a vulnerability is discovered within a traditional vehicle, the faulty component and the corresponding run of affected vehicles are physically recalled with the defect replaced/repaired. Such a recall provides the consumer with some hesitance; however, it is quickly supplemented with reassurance and a physical demonstration that the issue was identified and rectified (DVSA, 2014).

In the world of AV’s, this is going to be instead based on software version control and OTA updates, which is a far worse emotional proposition for the current consumer. As for software defects, in place of a physical recall; once a vulnerability is identified, developed and tested, a patch will be delivered via OTA update (Hashem Eiza & Ni, 2017). The efficacy of this is yet to be proven with such a critical system at such a large scale.

OTA will likely be adopted as the norm in the future, with Tesla applying the technology in vehicles with relatively few major issues as of yet, rolling out updates that can even change core systems such as breaking. However, they benefit from a fleet size nowhere near as large as that of legacy OEM’s. This coupled with a target demographic that is generally wealthy and technologically literate is also more likely to be accepting of such technologies (O'Kane, 2018).

Tech companies, however, are worse for maintaining ongoing support in comparison to OEM's. For example, the expected support cycle and updated frequency vary wildly between android skin deployments from different smartphone manufacturers, often leading to delays with critical updates resulting in a total support period of only about two years (Savov, 2018). This presents a problem when pitted against the ongoing physical and software support that is provided by vehicle OEM's and their service providers over an average vehicle lifespan (in the US) of 11.6 Years (BTS, 2016).

In the smartphone world, this results in a bias as Google produced hardware gets first priority with critical updates due to their ownership of the underpinning Android operating system, while other manufacturers trail behind at their own pace, often with less time to adapt due to less foresight and access to the forthcoming developments (SRL, 2018). Resultingly the latest security updates and features can be delayed or may never even see release. If such a model is replicated within the AV space, such delays could result in malicious security breaches, accidents and even fatalities (Amoozadeh et al., 2015).

2.2 What is the Current Trajectory of AV's

With record amounts of capital being invested in the direction of AV's, there must be a clear end goal, at present that appears to be full L5 Autonomy. The current directive that's evident from almost all competitors is the race to be first to market with a truly autonomous mobility solution. From a business-oriented perspective, this is logical, as first mover advantage in an industry as ripe for disruption as Automotive would be incredibly powerful and lucrative (Keeney, 2019), with estimations by Intel of a $7 Trillion global opportunity in this space by 2050 (Intel, 2017).

However, from the analysis of current literature, there is little to no cohesion between competitors around a practical large-scale launch for AV's. There are partnerships in hardware and software, especially with SOC (system-on-chip) manufacturers such as NVIDIA and Intel (NVIDIA, 2019). However, there is no collaborative rollout/adoption plan as is often seen with technologies such as 5G, where although different companies remain in a competitive space, they are required to roll out delivery and standards harmoniously (Ericsson, 2018).

Without cohesion within the industry or via government incentive, it is likely that the first to market will set the bar with pricing, availability, convenience and safety/regulatory standards (MacDuffie, 2018). However, the first mover advantage with technology so new could act as a double-edged sword as the hype around AV's coupled with their promised safety benefits, often emphasised by the very same companies, resulting in extremely high expectations from the public.

This is evident from the disproportionate media coverage of vehicles with autonomous features in perspective to the 92% of vehicular deaths in the US attributed to human error (NHTSA, 2015). This is also prevalent in the first AV fatality caused by Uber, as while the failure of the self-driving system needs investigation, the accountability shifted to the brand/technology, not the human safety driver. This is especially curious as it transpired that the human driver was allegedly watching streamed content at the time of the crash, demonstrating further that human supervision also beings in the variable of human error (Gartenberg, 2018).

A similar effect is observable with any Tesla accidents to such an extent that it was even called out by Tesla CEO Elon Musk in a series of tweets (Stevens, 2018). The impacts of this are articulated in the diagram on the right from Deloitte's US Survey, demonstrating that the press has a significant impact on public acceptance.

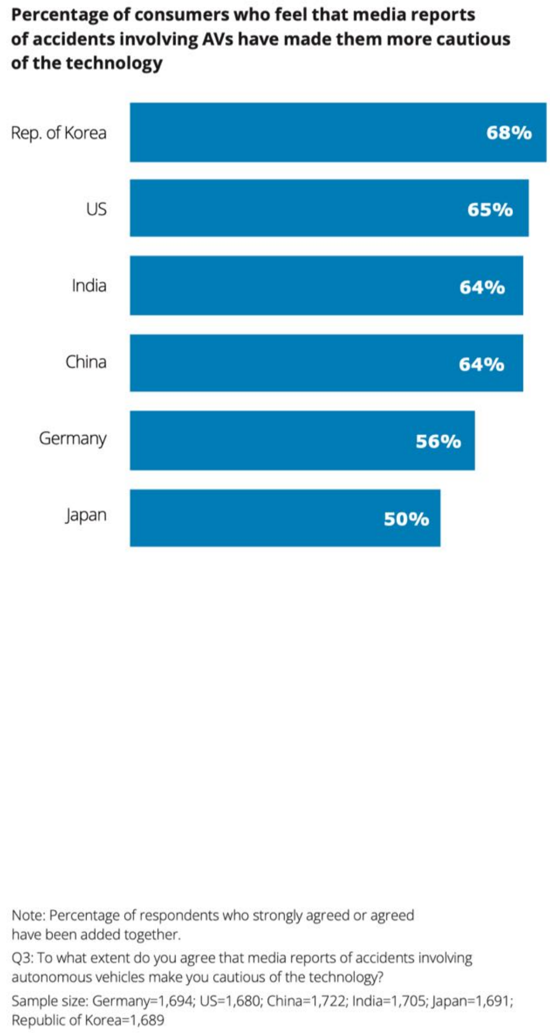


Figure 3 Customer Sentiment about AV's due to Media (Giffi & Robinson, 2019)

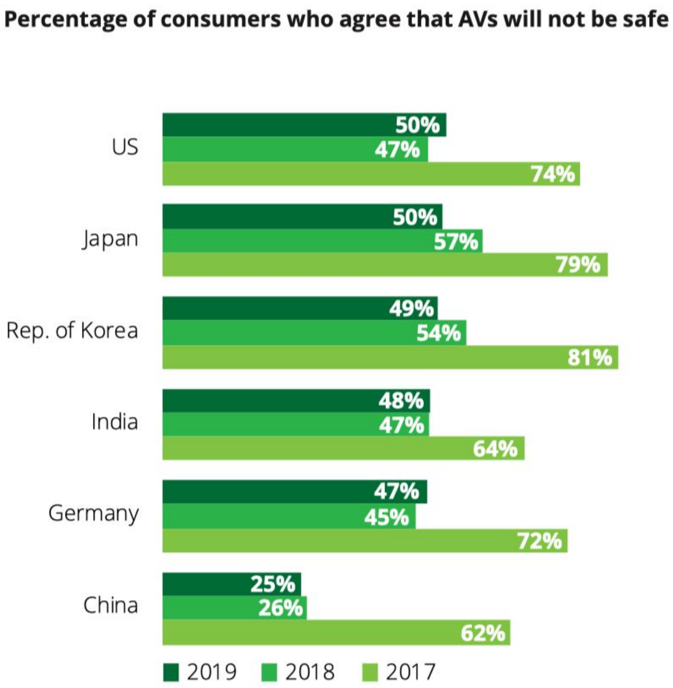


Figure 4 Survey of the Perception of AV Safety (Giffi & Robinson, 2019)

Note: Percentage of respondents who strongly agreed or agreed have been added together.
Q3: To what extent do you agree that fully self-driving cars will not be safe?
Sample size: Germany=1,733 [2019], 1,705 [2018], 1,574 [2017]; US=1,720 [2019], 1,730 [2018], 1,634 [2017]; China=1,735 [2019], 1,724 [2018], 1,633 [2017]; India=1,725 [2019], 1,728 [2018], 1,686 [2017]; Japan=1,717 [2019], 1,680 [2018], 1,656 [2017]; Republic of Korea=1,715 [2019], 1,722 [2018], 1,633 [2017]

Both of these types of events set back the public image of AV's significantly, interestingly however the majority of resentment in the case of the Uber crash was found to be against the brand itself and less about AV technology (BikePGH, 2019). This does not mean that it was unaffected however, as Figure 4 indicates, the negative perception of safety within AV tech is on a downtrend yet has reversed slightly in some markets.

We will likely overcome this as adoption increases and the reduction in accidents/deaths becomes evident verses that of traditional motor vehicles. Also, to be clear, if AV implementation scales effectively and the number of motoring deaths halved, that would still be a definite success versus the state of play today.

However, such accidents generally signify ‘edge’ cases which AV's have not yet learned. Such instances are often something that an attentive and experienced human driver would be able to mitigate. Training the AV's in this regard alongside ensuring safety is this exact process that the safety drivers are there for in L4 deployments today.

Such a scenario exemplifies the issue with the removal of human control unless it can be proven empirically. Therefore, it is right to guide AV’s towards being exponentially better than human drivers, as otherwise, these ‘edge’ cases will essentially be live testing of incomplete solutions, which is naturally not a good proposition if not managed and regulated effectively to ensure minimal risk and maximise societal good.

Some instances of this will likely be unavoidable, however with sufficient collaboration between regulators and industry (if malicious lobbying is avoided) such risks should be more manageable and transparent, therefore so should any resulting press.

This could attribute to Waymo’s sheepishness to deploy fully autonomously without safety drivers, especially as their CEO pressed into stating that their AV tech would not have allowed a death similar to that caused by Uber (Ohnsman, 2018). This will likely come back to haunt Waymo in the press once the first fatality from one of their solutions does occur even if unrelated.

All of this plays into an argument around societal good versus neoliberalist capitalism, as in the short-run it may be more profitable to push adoption of L5 sooner and maintain individualism in the world of autonomy, with the wealthy gaining access to the benefits of L5 at the detriment of transport as a whole. If this gets translated into how we legislate AV's it may have further detrimental impacts, as given the promise of the technology, accepting a sub-par reduction in road deaths to release the technology sooner would only realise a fraction of the technology's potential. Therefore, this will need to be taken into consideration by governments and the international community on behalf of society. This is going to be especially crucial in the coming years as the current race to L5 is being driven predominately by big tech, which has a history of innovating first and succumbing to regulation reactively after, as can be seen by the accrual of Facebook scandals and a general resentment to some of silicon valley's practices of late (Wong, 2019).

The public desire for Governments to act on their behalf to prevent corporate interests is evident internationally as can be seen from the Deloitte Automotive Consumer Studies below:

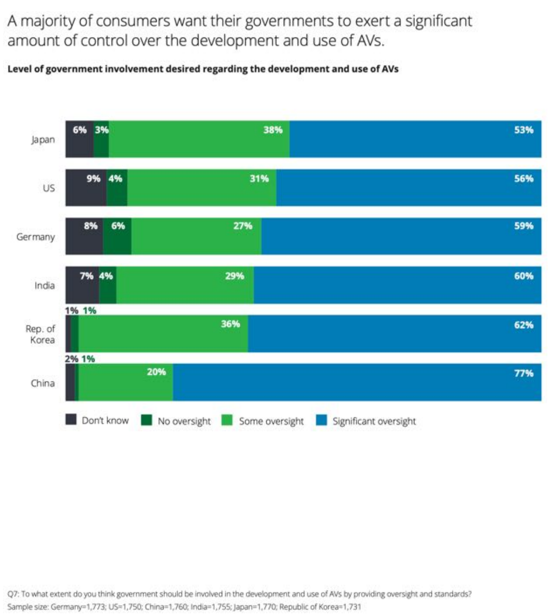


Figure 5 Preference in Government Regulation of AV's - Global (Giffi & Robinson, 2019)

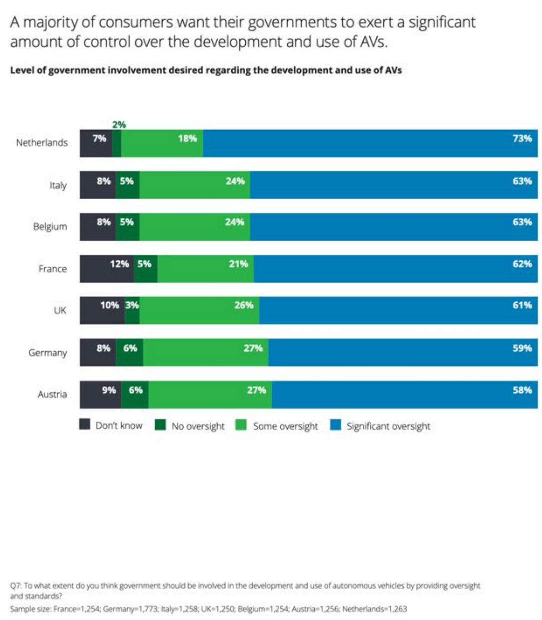


Figure 6 Preference in Government Regulation of AV's - Europe (Schiller & Robinson, 2019)

2.3 Supporting Developments and Technologies

2.3.1 Mobility as a Service (MaaS)

Introduction

The shift to MaaS has already begun as can be seen by the mass adoption of ride-sharing services such as Uber and Lyft (Schaller, 2018). This coupled with the decrease in vehicle ownership due to an uptick in finance leasing (now the most common way to 'own' a new car) results in the perfect set up for the traditional vehicle ownership model to become a thing of the past (FLA, 2018).

If successfully deployed, AV operated ride-sharing services should become so affordable that traditional ownership (initially in urban areas) will see a reduction to eventually become an absolute minority, with those choosing to maintain ownership likely doing so to use the vehicle as an asset to drive autonomously on their behalf and generate passive income (Keeney, 2019).

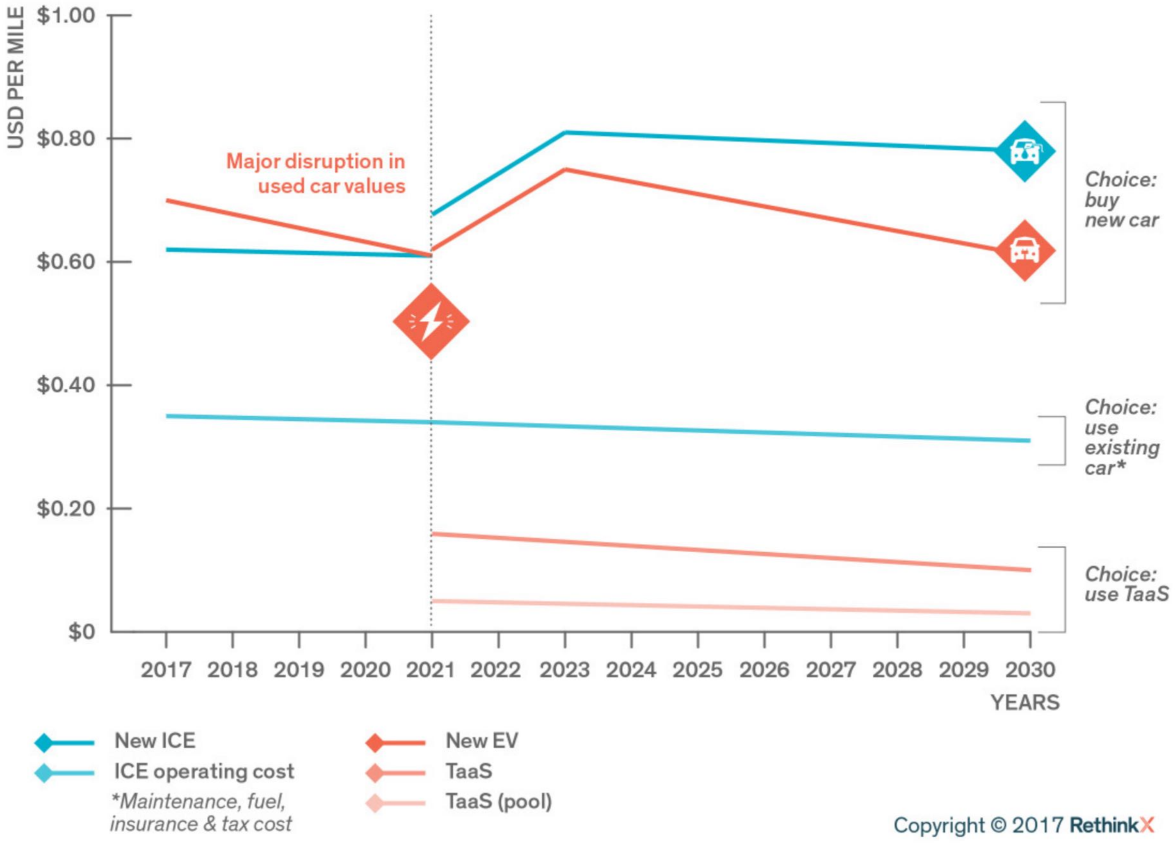


Figure 7 Cost Per Mile Predictions (RethinkX, 2017)

This section will further explore the shift to mobility as a service and its implications.

The Millennial Shift

Alongside being the first generation to experience stagnation in generational income progress, millennials have generally been perceived as far more scrupulous with their finances. This is due to a multitude of reasons including being raised during an economic recession and record austerity alongside having less earning potential and a higher likelihood to be renting property for the majority, if not all, of their adult lives (O'Connor, 2018).

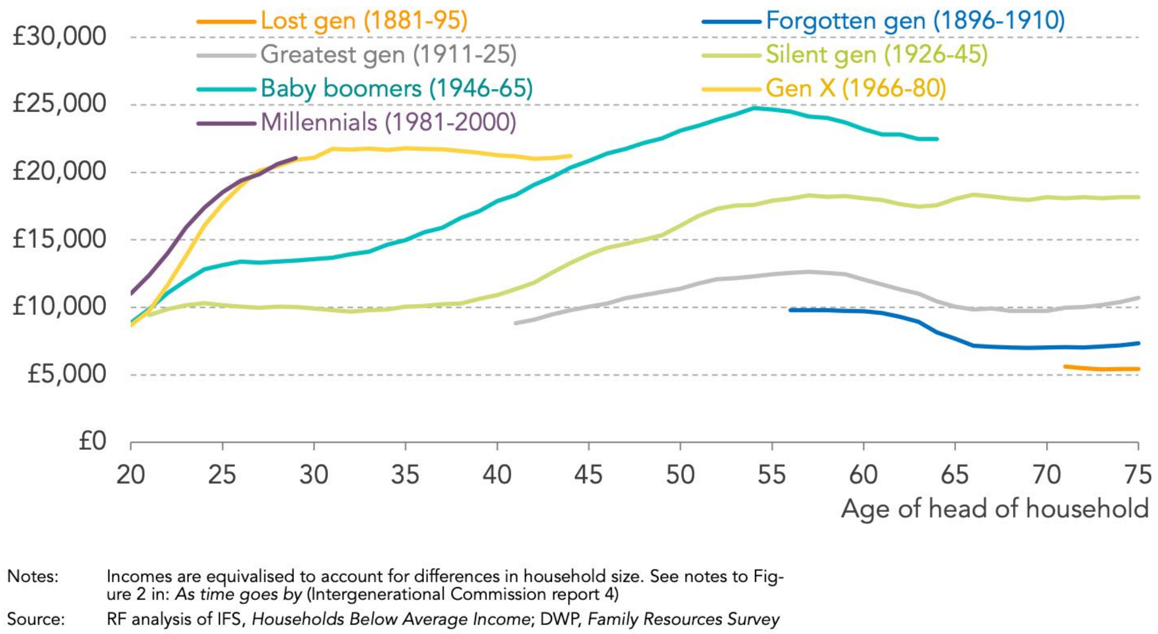


Figure 8 Generational Income (IC, 2018)

As a result, this has created a marketplace tailored for both millennials and future generations which has been dubbed 'the sharing economy' (Weitzman, 1986). This can be utilised by all but has explicitly been internalised by the younger generations due to its evolution being directly linked to technological progress, and in turn, technical literacy; As a result, services on demand have become the norm in many aspects of modern life (Hamari, Sjöklint & Ukkonen, 2015).

The coupling of the rise in access to mobility services alongside a greater consideration for environmental impacts has resulted in younger generations beginning to consider opting-out of vehicle ownership, something that was previously considered a social rite of passage within the middle class in much of Europe, and especially the USA.

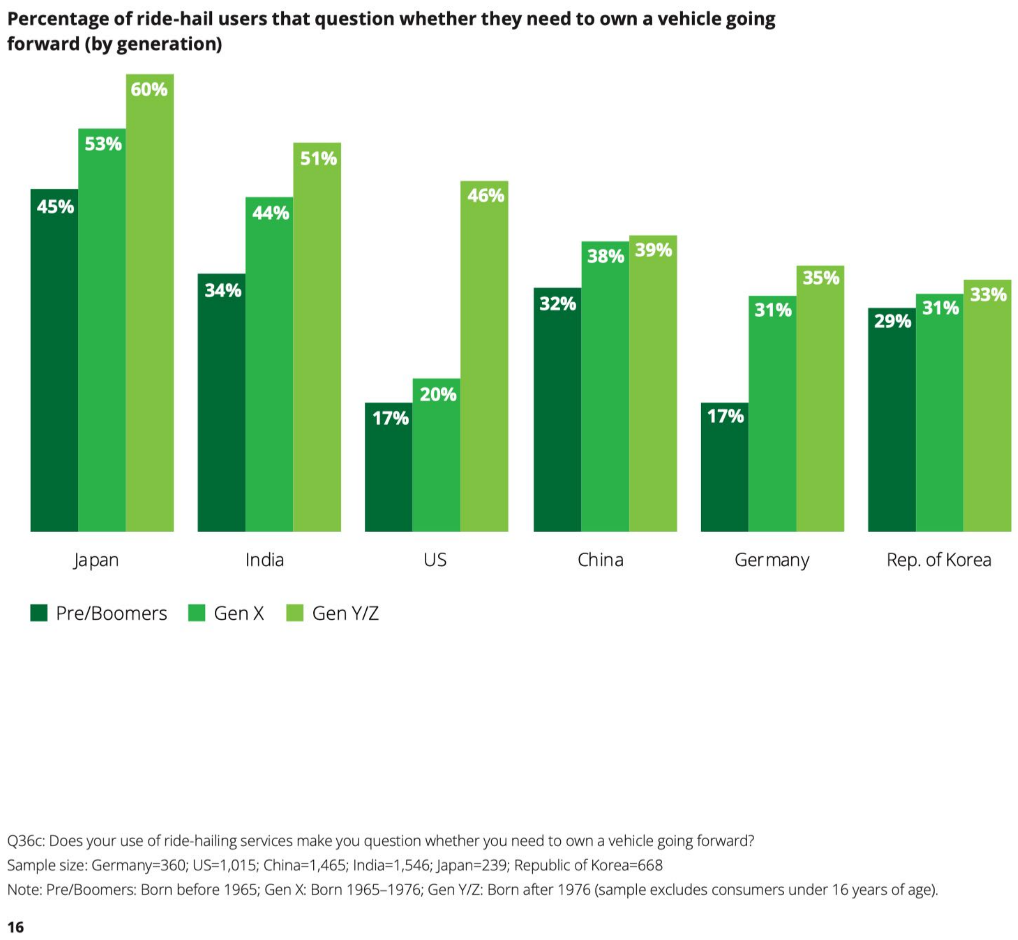


Figure 9 Survey of the need for a Personal Vehicle by Generation (Giffi & Robinson, 2019)

While this is beneficial for the set-up of AV's and many of the associated benefits, it's worth noting that there is a possibility for detrimental consequences too, as some studies have found that the addition of ride-hailing services has actually caused a net increase in the number of vehicles present on our streets alongside an uptick in fatalities (Barrio, Yi & Hochberg, 2018). Therefore, this demonstrates that if not managed carefully through regulation and city planning, there is the potential for an AV dystopia with increased and inefficient traffic that may create as many issues as it resolves (Millard-Ball, 2019).

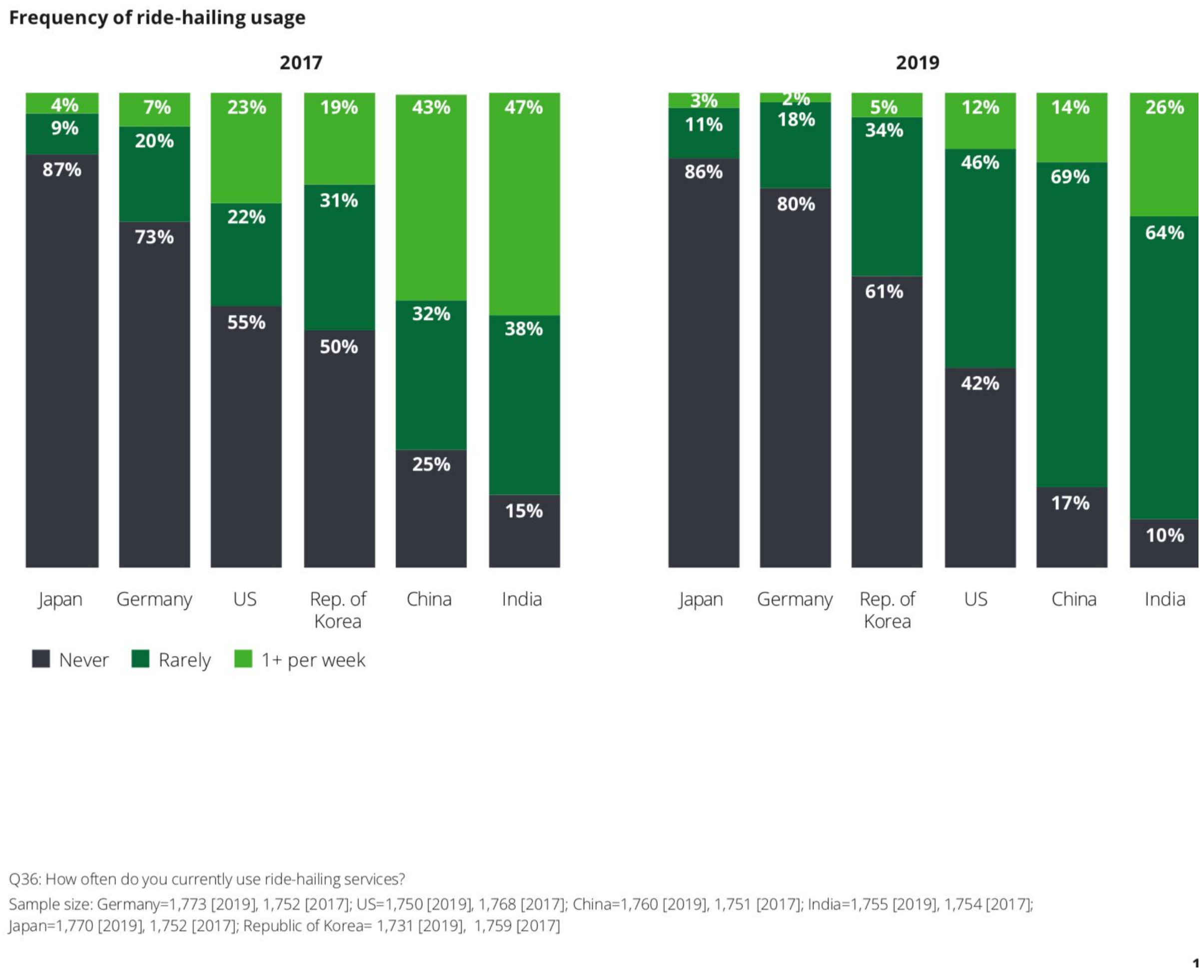


Figure 10 Frequency of Ride Sharing Usage (Helbig, Schiller & Proff, 2017)

It's also evident from the charts above those western countries which have vehicle ownership heavily engrained within their culture seem to have less of an innate desire to enter the sharing economy (Moeckli & D. Lee, 2007), with the delta's over two years being relatively flat and even decreasing, which is strange considering perceived increase in desirability of such methods of transport.

On the contrary, developing countries may find themselves to be the biggest beneficiaries of developments within shared mobility, as an ethos of sharing is already culturally ingrained. Therefore, the reduction in cost per mile that technologies such as AV's will likely be of greater benefit to such markets, partially due to lower income but also due to not being tied to asset-based ownership (Keeney, 2017).

Commercialisation

As mentioned, the two main disruptions to the current ownership and leasing models will be the increase in MaaS and the resulting decrease in personal vehicle ownership.

For this to be successful, there will need to be a massive disruption to the current set up of the automotive and auto-leasing industries, with automotive captives being especially under threat, as the models for managing risk in a sharing economy vary wildly to those associated with current leasing standards.

To prevent being caught out by the shift in consumer behaviour, any firms providing automotive finance will need to remain extremely attentive to consumer behaviours and begin preparing for the worst; as if AV technology is proven effective then the switch between the economic models could be extremely rapid. This can be especially detrimental as finance companies have billions based upon the guaranteed future value of leased vehicles. Reconfiguring these into a sharing economy and retaining profitability will be extremely challenging if caught off guard (Deloitte, 2018).

2.3.2 Electric Vehicles (EV's)

EV's are due to disrupt Automotive history following the success of Tesla and the societal shift towards more efficient and environmentally conscious mobility solutions. This brings a plethora of benefits such as reduced maintenance due to less functional parts, a lower centre of gravity (due to battery packs) and a far cheaper running cost per mile (Ergon, 2018). In addition, electric vehicles tend to include the latest driver assist systems and in turn, rarely include hydraulic steering. As mentioned previously, not only does this reduce maintenance costs, but it also acts as the prime set up for a connected/autonomous vehicle as if it is electric, it is likely to already have the majority of the components required for self-driving. Therefore, the convergence and increase in the adoption of electric vehicles could help propel and accelerate the transition to AV's. The probability of this seems all the more likely as can be seen below by the increase in public acceptance of alternative power trains between 2018/2019.

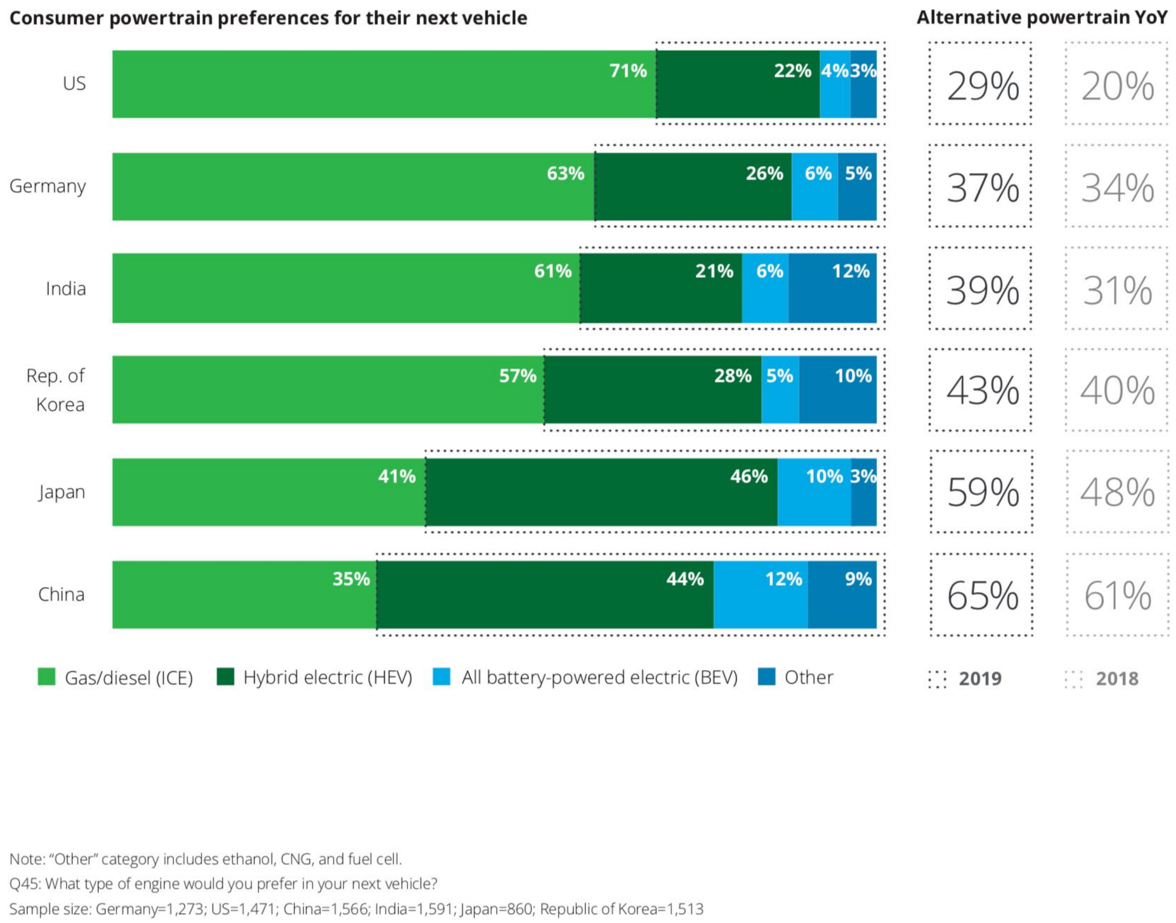


Figure 11 Consumer Powertrain Preference (Helbig, Schiller & Proff, 2017)

2.3.3 IoT & Smart Cities

The necessity for integration between the Internet of Things, Smart Cities and AV's is also further preached by academics and futurists as a requirement prosperous implementation of AV's. While the exponential increase of these technologies is already underway and essentially inevitable; there has been a lack of well-defined and enforced standards resulting in various security issues both current and forecast (Hossain, Fotouhi & Hasan, 2015). This is problematic as Vehicle to Infrastructure (V2I) connections are deemed to be a key component if AV's are to be successful in cities. The infographic below by SAP holds some predictions for this space:

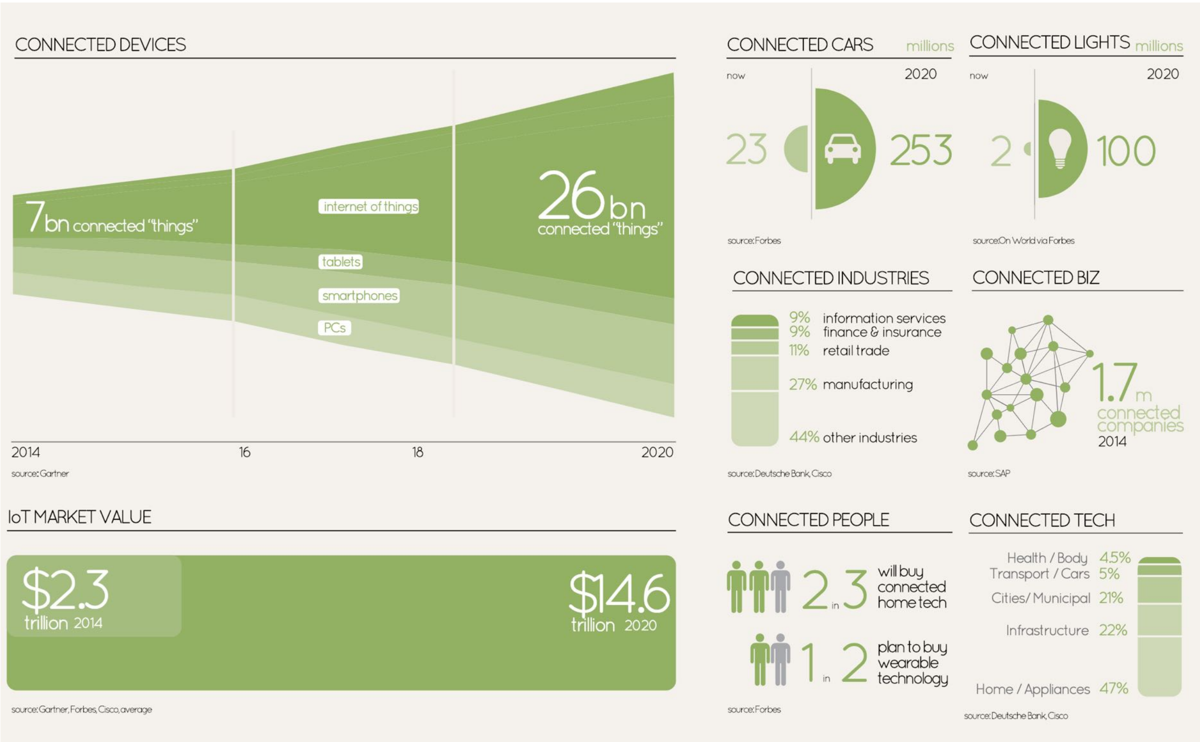


Figure 12 SAP IoT Statistics (Tomasevic & Kersley, 2018)

An example of such technologies is already being trialled today by Audi; however, it is only available to specific models, in a select few cities, with only compatible traffic lights (Volkswagen, 2016). This may also actually cause negative impacts as human drivers may interpret a countdown as a challenge rather than a warning which does not result in the perfect synchronous use of this information as would be the perceived case with AV's. This coupled with the myriad of limitations including; brand, city, location, compatibility and security concerns does not paint a promising picture for these technologies in the foreseeable future without a significant and rapid evolution (Gea et al., 2013).

2.3.4 Blockchain

Blockchain as a technology has been accelerated significantly since the Bitcoin bubble brought it into the public eye, with large banks such as JP Morgan Chase producing their own currencies in search of the potential benefits of this technology (J.P. Morgan, 2019). As this evolves, it could be argued that such technologies will continue to be applied in new areas. For example, AV's could look to utilise it to share essential data amongst vehicles in a highly secure yet auditable way. While this may not immediately bring benefits within the current trajectory of level 5 vehicles, once enhanced V2V (Vehicle to Vehicle) and V2I technologies begin to develop, blockchain could play a key role (Rowan et al., 2017). It could also bring security benefits to OTA updates which are currently one of the weakest points within IoT and AV's; this could, therefore, mitigate some of the leading safety, security and privacy concerns (Boudguiga et al., 2017).

2.3.5 5G

The mass adoption of 5G will be being rolled out across the world in the next half-decade or so, with 5G networks being made available to the public in select locations as soon as the end of 2019. 5G brings with it some great promises with regards to bandwidth, latency and availability; eliminating many of the issues with our current strained 4G/LTE infrastructure (Andrews et al., 2014). This also produces a new set of challenges such as a reduction in cellular range due to the higher frequency radio waves required to produce the benefits above (Sanchez, Sanchez-Picot & Rivera, 2015).

If this technology delivers on its promises, it may unlock a vital element of the futurist AV proposition, as the network could prove to be the backbone for V2X (vehicle to everything) connectivity (Molina-Masegosa & Gozalvez, 2017).

These two technologies could also potentially be merged creating a mesh network of interconnected 5G vehicles which share (and potentially monetise) any spare bandwidth by acting as a repeater for the 5G network, helping alleviate the range issues while increasing the versatility of the network during peak times.

2.4 What are the biggest blockers?

2.4.1 Industry Collaboration

Although there have been strategic partnerships formed between various OEM's and tech companies, industry collaboration towards a cooperative AV future is yet to be pursued at scale. NVIDIA is probably the most significant driving force of collaboration at present; however, this is predominantly due to its commercial interest as an AV hardware/software manufacturer. They have made strides in the right direction as their AV software development platform is open so that various parties can integrate and the developer community as a whole can gain insight (Burke, 2019).

The prominent issue with collaboration is around the IP underpinning the workings of each competitors AV solution, as they all race to be not only the first but also the best to market. As a result, presenting their solutions to regulators in a traditional sense would enable not only public scrutiny but also the potential for competitors to acquire the IP. This in turn further increases the complexity of regulation and poses many questions around the auditability of AV's.

How are crash/regulatory investigators meant to audit driving technology that has been developed behind closed doors and has utilised many machine learning and AI algorithms from the net aggregate of millions of miles travelled? The result would be challenging to be interpreted by the creators, let alone a government body who as a generalisation have a track record of struggling to regulate complex technologies (Wadhwa, 2014) and would also have to understand a plethora of different solutions by various competitors. Therefore, a dependence would be made upon the availability of the creators, which could become challenging or near impossible if bankruptcy were to happen and the vehicle was not auditable in some standardised way.

This all leads to a winner takes all ecosystem, to which there are benefits in theory, as the populous do want the best system to prevail. However, if the system that is deemed the best in most scenarios prevails to the determent of other systems which may still be superior in some scenarios but not overall, these efficiencies will be lost resulting in potentially dire consequences. This would not benefit the consumer and would also be in opposition to the principles of free-market capitalism.

2.4.2 Safety

As mentioned throughout, safety is one of the key benefits touted as a result of the mass adoption of AV's. That sentence in itself essentially highlights the issue, as in the interim, we will be looking at a world for many years where AV and non-AV's will share spaces. This presents a problem as the number of variables increases exponentially for every unknown driving parameter. As a result, every human and independent level 5 system will be at odds, increasing complexity thus omitting the opportunity for computational efficiency (Friedrich, 2016).

An effort can be made to mitigate this to an extent through V2V communication, however, due to the lack of industry collaboration coupled with the simple fact that to galvanise the benefits a significant adoption of connected vehicles would be required. Therefore, without change to the current pace and direction, the benefits are not likely to be realised anytime soon (McCarthy & Flood, 2017).

This together with the adamance for development straight to L5 has repeatedly surfaced the aforementioned 'trolley problem'. This argument holds some merit in the current race to L5, as although the situation theorised is incredibly unlikely and in any case would be far more complex than the simple trade-off choice that it is broken down to a binary moral decision, it does bring a valuable conversation around the ethics of autonomous vehicles to the table.

However, in retort, it could be argued that a successfully integrated deployment would make this issue statistically irrelevant. As in the ideal implementation of AV's where V2X connectivity is established and vehicles navigate based on shared governance/data, the risk and probability of altercations could likely be tailored within the configuration of the system. As a result, there could be the potential to set the probability of a non-fatal altercation to be effectively zero, or if this caused determent to traffic flow look to improve safety to be 90-99% as efficient compared to human drivers. This should help reduce/resolve the moral conflicts in closed L4 scenarios; however, the overall debate for L5 vehicles will likely continue.

2.4.3 Policy and Laws

There is significant work being done globally around the laws and regulations of AV's and other disruptive technologies. As mentioned in IoT and Smart Cities earlier, standardisation and security have already become a significant issue (Zhao & Ge, 2013) and IoT is due to expand exponentially in the coming years as seen in figure 12.

Hence demonstrating the inability of government and the international community to regulate and standardise substantial technological changes as recently as the last few years up until the present day (Irons-Mclean, Sabella & Yannuzzi, 2019). Therefore, this does not give much hope for connected AV's in this regard.

The initial public driving tests conducted by Google before Waymo was spun out were initially conducted without even informing the government as 'technically' it was legal given there was a human safety driver present (Burns & Shulgan, 2018).

The slow adoption to policy change and also limited technical understanding by government bodies has historically caused many issues with such technological changes, and sadly it does not seem that we have overcome this today.

There have been some inquiries into the practice of 'agile' law-making (WEF, 2018), however, even drafting the polices to begin utilising such developments will take a significant amount of time under current legal frameworks (Kaji et al., 2017) which is concerning as companies look to debut solutions as soon as 2020.

2.4.4 Infrastructure

One of the great unknowns for the current rollout of AV’s is its prospective interaction with infrastructure. It was essentially concluded in the early quest for autonomy that it would be easiest for AV’s to abstain from real dependence on connected infrastructure, but instead being able to navigate as a human would. This is essentially the goal of L5; however, critics state that the complexity of this is far too immense. At times, a human driver will not know what they are doing or what it is that they are meant to be following, posing an even more significant challenge for AV’s. Live testing of AV’s has confirmed this risk, as adverse or even simply non-optimal weather conditions have been found to cause issues with current AV operations. Most accidents thus far could also be attributed to 'edge' cases which as described is to be expected with such a multivariate approach (MacDuffie, 2018).

V2I integration could be invaluable in mitigating this shortfall. Alongside this, many of the promised benefits that would be reaped from truly conned AV’s will not be possible without the transition to smart interconnected infrastructure, especially in cities if congestion is to be tackled intelligently, or at all (Shin, Park & Park, 2018). The issues within infrastructure break down into two parts:

Legacy Infrastructure

Existing infrastructure will still need to be maintained and potentially improved to accommodate the adoption of AV’s. The reason for this being that computers will likely struggle more than a human driver may when interpreting unclear signs or road markings due to wear, graffiti or obstruction. As a result, AV’s will likely be less or even not at all competent in some roadways, the resolve to which would either be refreshing the infrastructure or reducing the AV’s dependence on it. Both of which require the assistance of government and incur expense, with a sub-optimal result (MacDuffie, 2018).

Connected Infrastructure

Truly integrated infrastructure would arguably be the ideal scenario for autonomous vehicles, and while it may not be finically viable everywhere, it will at least need to be consistent. For example, if a city is to unlock the potential benefits of AV's fully, it should ensure that all infrastructure is connected and monitored enabling the most optimal traffic flow and congestion management (Shin, Park & Park, 2018). Other than the upfront costs this also brings into scope other issues such as potentially aggravating social inequality. If the rollout of AV's is not fair and equal with accessibility, it could potentially isolate poorer neighbourhoods with worse infrastructure and mobility, thereby furthering any underlining class divide (Lim & Taeihagh, 2018).

2.4.5 Adoption

It is still uncertain whether the population will take to the mass adoption of these new mobility services and ownership models. This is made infinitely more challenging in a global perspective, as different countries have different driving cultures and complexities which not only will increase the difficulty for an AV system to adapt to local norms, but also brings different perspectives to the value of vehicle ownership (Moeckli & D. Lee, 2007).

For example, in this regard, America is exceptionally car-centric, with vast intersections and many parking spaces. Disruption of this model and 'way of life' could prove extremely challenging within itself as can be seen in Figure 13 below:

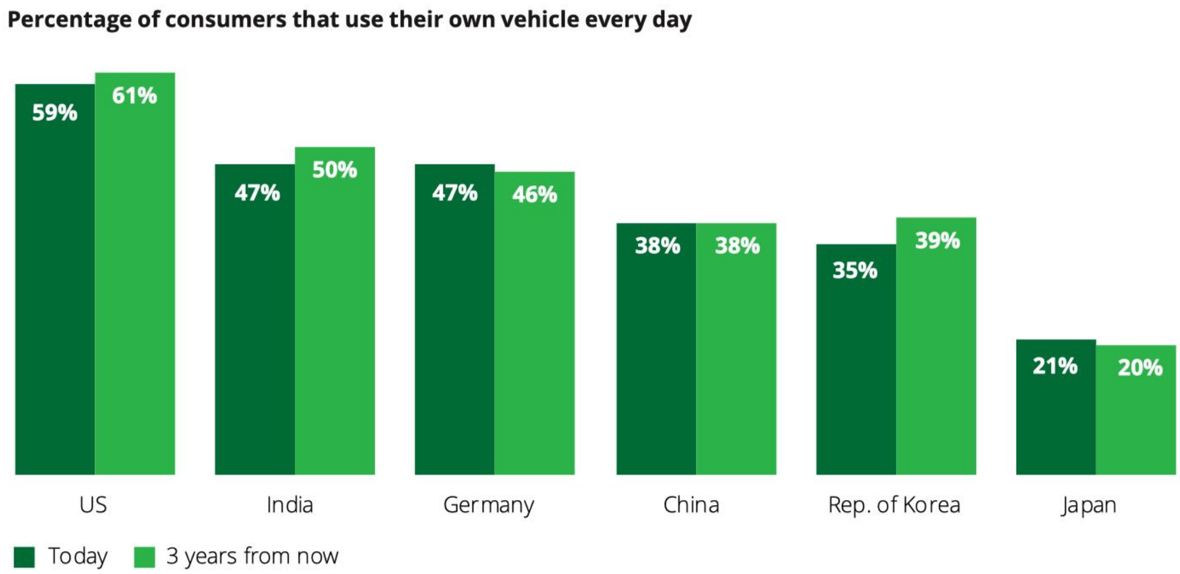


Figure 13 Surveyed Future Vehicle Ownership (Giffi & Robinson, 2019)

Q26–Q27: Please indicate how often you use each transportation method (today vs. 3 years from now).
Sample size: Germany=1,773; US=1,750; China=1,760; India=1,755; Japan=1,770; Republic of Korea=1,731

There are also questions raised about the fragility of AV's when interacting with humans, as if pedestrians are all but guaranteed safety, they may not think twice about crossing the road or checking for vehicles as they could put total dependence on the car's safety systems and prerogative not to harm humans. At worst result in unfortunate accidents if it is not feasible for the car to recover from the human interruption or just generally result in an increase in congestion caused by humans leveraging the cars innocence and compliance to cross at any time they please.

2.5 Outline Thesis

Built from the above sections, the thesis of this dissertation is based around the lack of a clearly defined rollout strategy for AV's. It appears from the research thus far that there is no real agreement/cohesion on the actual mass adoption of this technology. It is apparent that there needs to be greater alignment for there to be a successful and commercially viable rollout of AV's. This could potentially be tackled by working to pioneer connected L4 cities in situ with the development, testing and deployment of L5. Thus, enabling a more gradual shift in consumer and industry norms, reducing the sharp focus that is currently present on level 5 solutions in development. This would assist in relieving current media pressure which is partially responsible for constraining rapid development within the industry alongside providing a case study and test bed for the vehicles and their supporting technologies to be refined and adapted and governed within a controlled environment.

2.6 Industry Insights

Introduction & Summary

To affirm the problem statement contact was made with various sources from both the Automotive Industry and Academia to assess the thesis and the proposition within this dissertation. This included a member of FiveAI, one of Europe's leading AV start up's alongside academics from the University of the West of England who have had involvement in six multi-million exploratory Autonomous Vehicle Projects.

There was a general consensus to the ideas pitched within the thesis, with an agreement that the roadmap of AV's is not particularity well defined and that adoption is likely to come over the next decade or so, rather than imminently in the next few years. There was also agreement around the substantial technical and legal challenges that are still open-ended or are currently in the works but not yet delivered.

The following are the key points taken from these discussions which have fed back into the body of the dissertation.

Safety & Audit

In discussion with FiveAI, there was agreement that the current metrics that are focused on by the media surrounding disengagements (miles travelled without intervention of a safety driver) are a relatively weak measure of true AV progression. They are only released in states as a legal requirement and aren't a true measure of vehicle progression. This is because they are highly subjective and may also have negative impacts if safety drivers are encouraged to take greater supervision risks for the sake of such metrics. They also depend on extremely multivariate scenarios; therefore, this alone is not a robust measure. FiveAI published an open paper in this regard suggesting policy and reporting improvements, which explores similar themes to elements of this dissertation.

The Neoliberalist Approach

When discussing the current direction of L5 deployment and its societal implications with a member of UWE's Geography and Environmental Management faculty, a point was raised around the attribution of the current direction within the technology to neoliberal principles. This is because the general direction of the technology and in turn public policy is mostly being driven by the most prominent tech corporations which have massive lobbying power and a fiduciary duty to maximise profit to their shareholders. If this is not managed sufficiently by the international community, it could be at the detriment of future transport and society as a whole.

Technical Limitations

From discussions with a senior member at the Bristol Robotics Laboratory, agreement formed about the lack of maturity within current AV technologies and the supporting infrastructure. In turn, it is plausible that reasonable L4 solutions would likely be achievable; however, fully adaptive L5 was likely in the distant future. There was also an agreement that large technology companies may have accelerated the rate of change within the automotive industry which may prove to be detrimental in the future as it was an extreme reconfiguration for automotive, and just a 'moonshot' as it is for the likes of Google. Finally, a brief discussion around the opportunities for improvement to localisation as connectivity and sharing of data points increases, an excellent prospect for V2X vehicles. A mention of swarm robotics was also suggested as an area to investigate in this regard.

3. Autonomous Vehicles, further critiquing the current trajectory

3.1 Summary of Issues with the Current Approach to Adoption

As mentioned, it could be observed that the current path to adoption is driven in most part by neo-liberal corporate interests to become the first to market with little thought to the impacts on society. This is logical in a sense, as Waymo was initially spun out for Google's 'Moonshot' division, which by definition seeks to look "5-10 years into the future and aiming to invent new technologies and launch them into the world" (X, 2019). There is an altruistic aspect to this; however, Alphabet and its subsidiaries ultimately operate as for-profit businesses.

There is also a general acceptance that these projects may not succeed; several Moonshots have failed to deliver including jetpacks and augmented reality glasses (Mack, 2014). The spaces they have entered previously, however, have not been mature industries. In the case of AV's, Googles' intervention in a legacy, incremental and highly regulated industry has resulted in a mobilisation of OEM's into areas far outside of their comfort zone. As explored earlier this could have dire consequences as OEM's try to rapidly evolve their software competencies to keep up. The critical issue here is that Waymo does not need to succeed, and the software solution that they are producing does not require the massive investment in capital and manufacturing that is required actually to produce AV's.

This is, in essence, allowing Waymo to gain massive valuations as a tech company, with no inherent capability to physically deliver on the promised hardware, therefore making partnerships with OEM's will be key. It also means that if unsuccessful, the losses for Google/Alphabet are far less significant than for a partnered automaker, which could easily lose massive amounts of investment if AV's were unsuccessful. This skittishness was seen in what could have been a breakthrough deal for Ford that instead fell through (Carty, 2017). Since then Waymo has found successful manufacturing partnerships with the likes of Jaguar and Fiat-Chrysler (Rai, 2018); however, regulations and safety still have the potential to create a barrier.

This is being tackled in some part by governments and regulators, but fundamentally the reason we have a race to L5 as the direct replacement of a human driver is due to the industries perception that governments, policy and infrastructure will not change at a sufficient pace to accommodate for the rate of technological change.

Instead, the current approach is all too similar to previous tech conquests such as social media and online advertising/data aggregation. These technologies and their pace of change were and still are far beyond the grasp of most regulators which has resulted in their actions being poorly audited, with public interests suffering determent as a consequence. There is a risk of the same thing happening within the AV space if common ground is not found soon (Bliss, 2018).

This is not to say that there is no place for the conquest of L5, but instead, that on the path to achieve this we need to identify the true synergies based on the pain points of customers (the public). This has been the fundamental disruptive force within big tech, exploring blue ocean space; however, within AV's this requirement gathering seems to have been omitted. Instead, the goal seems to be a BAU replacement of manually operated mobility services such as Uber and Lyft with L5 autonomy.

This on its own may bring about some of the promised benefits of AV's by improving driver safety, however, the myriad of issues it unlocks and the immense complexity of tasking new technologies with something that arguably human drivers cannot do perfectly. While this is a great challenge and marvel within the space of computer vision, machine learning and AI, it does not fundamentally play into the core mathematical principles at which computers excel.

For this to be achieved a far greater level of collaboration would be required, as simply replacing the human driver does not bring about the majority of promised benefits that could only be actualised by significant integration between brands and infrastructure, especially within metropolitan cities (MacDuffie, 2018).

The current trajectory is forecast to achieve this; however, it would be in the distant future, and a pre-requisite would be the successful mass adoption of L4/L5 AV's, which under the current course looks unlikely.

This is amplified with the uncertainty of public acceptance, as failing to deliver in this regard could result in any meaningful adaption AV's being delayed by years or even decades. This would not be beneficial for anyone, from corporations to citizens and their governments. Finding cohesion is especially prevalent with external factors such as climate change and growing public health concerns due to pollution in urban areas requiring an immense drop in the consumption of carbon/toxin-emitting resources (Blunden & Cecil, 2018). This would be significantly improved if city optimisation is realised, however with the current BAU approach this will be unlikely to be at the scale promised, and it may even bring detriment if vehicle miles travelled increases in situ to the increase in mobility.

3.2 Elaborating upon the Oversights of the current path to AV Adoption?

3.2.1 Introduction

Building upon the opportunities and blockers explored so far; this section will look to summarise the fundamental oversights which will inform the proposal of this dissertation.

3.2.2 Rollout, Collaboration and Regulation

As highlighted, there is a definitive lack of solution orientated collaboration in the AV space within both the respective industries and their supporting governments. While certain companies and regulatory bodies are working closely together to shape for individual markets, countries and states, there is little collaboration on a global front or in between multiple OEM's at a truly significant level.

This does not set the stage for the promised AV future, as without a single cohesive shared platform for V2X communication across competitors, then the promised smart city and its autonomous mobility efficiencies will not be realised.

The most significant contributor to this aside from individualistic interests is the slow pace of standardisation and governance, especially within new technologies. The consequences of this have already been seen with the oversights already present in maturing technologies such as IoT. Without a re-work of current legislating practices coupled with a deep technical understanding of the challenges faced it is likely that competitors will outpace and dwarf any efforts of regulation which has historically been very common, especially with big tech (Hayduk, 2016).

Facebook's current troubles being a prime example of this, as their goal of connecting everyone has resulted in a record increase in loneliness and depression within teens enhanced by an extremely liberal attitude to data usage, advertising and privacy (NYPost, 2016). This is in part a failing in regulation, but it can also be attributed to the rise in surveillance capitalism (Kelly, 2019).

If this is not understood and regulated against, then there is a potential for such practices to seep into the AV sphere, especially with big tech players involved in current developments

(Zuboff, 2019). This may further heed public resentment as if autonomous transit leech’s data and serves intrusive adverts then it is likely not a good proposition for the public.

Therefore, if privacy, agency and general principles for societal good aren't ingrained into AV development at a base level via industry cohesion and standards, then the disparity between competitors’ solutions and their implications will be incredibly diverse. The massive variance further adds to the challenges of regulation which will likely further delay any significant regulatory progress.

Because of this, a large-scale collaboration to dictate the base technical and regulatory standards alongside engraining societal principles AV’s should be considered a requirement by either governments or private industry. If this realised, then it will likely make the process of rolling out these technologies in any meaningful way unnecessarily complicated and significantly less likely, due to the complexities of regulating and an industry that would be subject to such extreme variance.

3.2.3 Lack of Convergence with Emerging Technologies

Although the opportunities of AV's supplemented with future technologies is often discussed, it is generally only theoretical, and while there has been some commitment to the convergence of certain technologies (NHTSA, 2018), no single entity seems to be explicitly seeking maximum utilisation of emerging technologies. Instead, the race to L5 is taking precedent.

The potential result of this will be that technologies will need to be adapted into AV use once competitors decide that the requirement is present, rather than being co-developed to reach optimum efficiency. An example of where this could be crucial is the use of 5G, or at least some form of mid-range communications platform to enable V2V and V2X communications. Currently, some brands are doing this by adapting traditional 2.4Ghz Wi-Fi and similar existing technologies. While this may be more practical in the short run, incorporating 5G into the designs today will potentially enrich and assist with the rollout of the technology in the coming years.

3.2.4 Public Uncertainty/Scepticism

As discussed already, public uncertainty with the transition to Autonomous Vehicles is going to be one of the key blockers within the rollout of this technology yet approached correctly it could also be an opportunity. As it stands however due to the majority of developments being behind closed doors, with little to no government involvement, uncertainty is at an all-time high.

Until there are clear strides by impactful authorities to legitimise the transition to AV’s enabling them to appear as more than just an expensive pilot, there will likely be little success in commercialisation and mass adoption.

To rectify this an individual country or coalition will need to take a decisive step towards the mass implementation of AV’s within a selected space, for example, a capital city. Once a working concept is proven then public opinion will likely begin to shift as many will seek to alleviate themselves from the pain points of city commuting (McCarthy & Flood, 2017).

If successful the first entrants into this space will dramatically increase the value proposition of their transport infrastructure, providing a template and insight into the future, coupled with a set of lessons learned from their implantation.

This will then be able to be adapted and scaled for similar adoption in urban centres across the world, in essence kicking off the transition towards a fully autonomous future.

3.3 Key Oversight: The Race to the Bottom

3.3.1 The Race to the Bottom: Explained

This section will explore this perspective based on predictions due to the lack of literature found from extensive research within this space.

The key oversight that seems to have been omitted by most every thinktank and publication is the potentially extreme results of public uncertainty, scepticism and outright rebellion that is entirely possible within the current path to AV adoption.

What is meant by this, is that the current emotional bias against the automation of vehicles that has been seen both within the industry itself but by a majority of the population has inclined towards the fact that public sentiment is not yet prepared for the new technologies or shift in ownership.

Unlike previous case studies of automation becoming a daily norm, such as the removal human lift operators in exchange for buttons and a prioritisation algorithm, the removal of humans from car's feels far more complex and uncertain. This is especially prevalent as the technologies involved are so dense that they are barely understood comprehensively by the majority of the automotive and technological sectors and the general public.

As mentioned initially this is a sophisticated software problem and not one that (at least with the current trajectory) is to be resolved with mechanical or logical embedded solutions. Instead, an extremely complex application of neural networks and a plethora of inputs tailored by self-learning algorithms and developers who likely will not be able to be held accountable naturally manifests a 'fear of the unknown' to the average consumer.

The result of this, as explored in the previous sections is a level of scepticism and excess media attention to all autonomous vehicle trials, even when statistically there are 1.35 million deaths per annum from traditional human-operated vehicles (WHO, 2018). This shows that until AV's are proven at scale, the emotional argument is going to continue to outweigh statistical logic when it comes to safety concerns around AV's.

Due to the lack of actual deployment of such technologies still being limited to extremely small closed pilots, the true detriment of this theory has not yet been observed to its full potential. It was witnessed at a small scale following the Uber crash, as they immediately suspended trials in the area even when evidence seems to point towards the safety driver not paying full attention coupled with an unmarked pedestrian making an illegal crossing. With Waymo due to begin scaling its solution over the next two years increasing their fleet 100x (Hawkins, 2018) this may soon be observed.

3.3.2 The Race to the Bottom: Example

Now let us say that in a few years 10-15 OEM's and tech companies have released their L5 self-driving solutions, and the evidence quickly stacks to show that one system is statistically superior. Once highlighted this will immediately result in severe distrust of all other competitors, to the extent of a potential boycott or attempts to return/actively avoid all but the safest system (even if the variance in safety is as insignificant as a few percent).

Traditionally safety differences between vehicles have been more of a trade-off choice based on factors such as price, performance and availability. As the driver still maintains a sense agency over the safety of the vehicle. In the case of an autonomous solution with no override, this sense of agency is removed entirely. Hence a race to the bottom will ensue where all but the statistically best solution will be avoided, as the choice of AV solution will be the only point at which a consumer will be able to assert agency.

This would result in a complete halt to free-market style innovation resulting in a winner takes all ecosystem alongside the potential for an overdependence on one L5 solution provided by a private entity, which will likely form a monopoly and be near enough impossible to disrupt even with anti-compete laws, as is seen by the largest tech companies today.

Such issues are further fuelled by the emotional complexity of recalls and fixes in the case of AV solutions as explored in 2.1. If scepticism is already arising in solutions that are statistically worse than others due to edge cases causing fatality or injury.

The resolution via OTA update, or potentially the issue being caused by an OTA update can result in brand detriment the likes and scale of which has likely not been seen before, with impact potentially multiple times that of the emissions scandals. The ability to recover from this would also be highly unlikely, resulting in a downward spiral until the software solution is no longer viable. As a result, an OEM in this case would likely have to adopt a different, more successful software stack, most probably from the safest provider, which is further reinforced by public sentiment on the lack of OEM software competence in Figure 14 below. This would then loop back to the race for the bottom, and the winner takes all ecosystem that is likely to be formed.

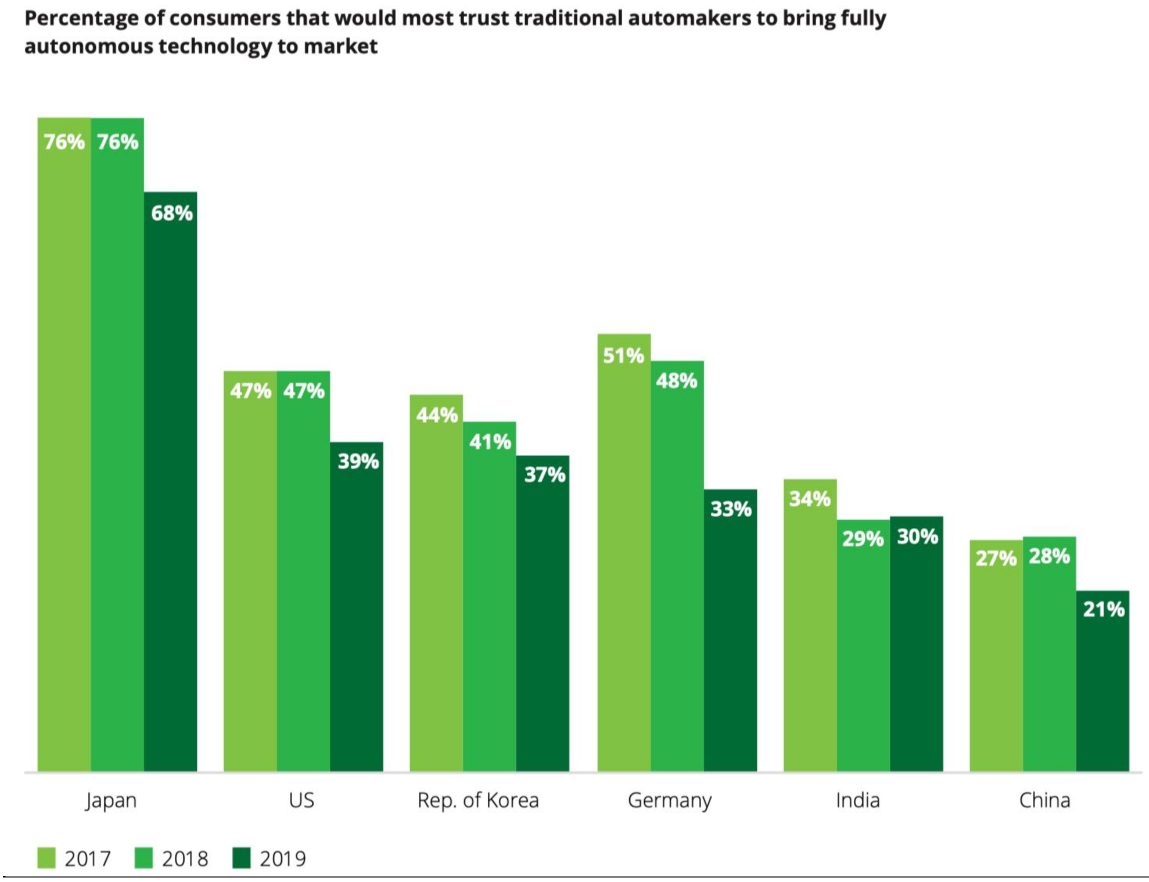


Figure 14 Consumer Trust in OEM's to Deliver AV's (Helbig, Schiller & Proff, 2017)

Figure 15 reinforces this prediction as the public sentiment from a Deloitte AV study shows that full L5 AV tech is not a high priority for today's consumers, who through years of individual ownership instead want more supplementary technology in their vehicles.

Category	Rank	Technology that:
Safety	1	Recognizes objects on road and avoids collision
Safety	2	Informs driver of dangerous driving situations
Safety	3	Blocks driver from dangerous driving situations
Safety	4	Takes steps in medical emergency or accident
Connectivity	5	Diagnoses and sends maintenance notifications
Cybersecurity	6	Enables remote shutdown of stolen vehicle
Fuel efficiency	7	Helps enhance fuel efficiency
Cybersecurity	8	Prevents theft by restricting unauthorized access
Fuel efficiency	9	Enables use of advanced lightweight materials
Environment	10	Lowers the impact on the environment
Connectivity	11	Enables vehicle-to-vehicle and road communication
Environment	12	Enables usage of alternative fuels
Cybersecurity	13	Prevents hacking into vehicle systems
Safety	14	Monitors the physical health of the driver
Environment	15	Assists in locating, reserving and navigating to a parking space
Cost efficiency	16	Coaches the driver to drive safely
Convenience	17	Automates tasks for comfort and convenience
Convenience	18	Enables interactive vehicle operational information
Self-drive	19	Enables full self-driving capabilities
Connectivity	20	Enables remote/automatic software updates of the vehicle
Self-drive	21	Enables high-speed, long-distance, highway 'auto-pilot' mode
Convenience	22	Enables hands-free interior controls
Self-drive	23	Enables low-speed urban 'auto-pilot' mode
Micellaneous	24	Enables the use of self-healing paint
Service enabler	25	Automatically pays parking and toll fees
Performance	26	Makes available adjustable settings to enhance vehicle performance
Micellaneous	27	Empowers customer to personalise vehicles
Service enabler	28	Allows the driver to control automated home systems
Connectivity	29	Allows use of smartphone applications through the vehicle dashboard
Service enabler	30	Provides notifications when places of interest are near
Convenience	31	Provides passengers with customised entertainment while driving
Convenience	32	Helps manage daily activities

Most useful Moderately useful Least useful

Note: Break points for most, moderate and least preferred technologies are derived based on percentage of times a technology is rated the best. Sample size: [N=1,246]

Source: 2016 and 2014 global automotive consumer survey, Deloitte.

Figure 15 Consumer Preference in New Vehicle Features (Bornstein, Rakow & Clemente, 2019)

This may however just be a result of Automotive marketing and 'trickle down' features that have constrained all but the owners of the most prestigious and costly vehicles from having access to embedded safety systems that have been available for years but held back from the majority of consumers until regulatory requirements stepped in is another question (Hyatt, 2019).

Any AV solutions are also not immune to this as substantial bugs and defects often found in core operating systems such as Android, IOS and Windows, and while the patching is generally effective, most phones and PC's are not in charge of a vehicle with the potential to cause harm. In the case of critical systems, with upgrades avoided due to uncertainty. This is another catch 22 of critical system development; however, it is an additional aspect of AV's that needs to be overcome. See the percentage of XP installs below which Microsoft has not supported since 2014, with an exception for critical systems in the US military (Hsu, 2018).

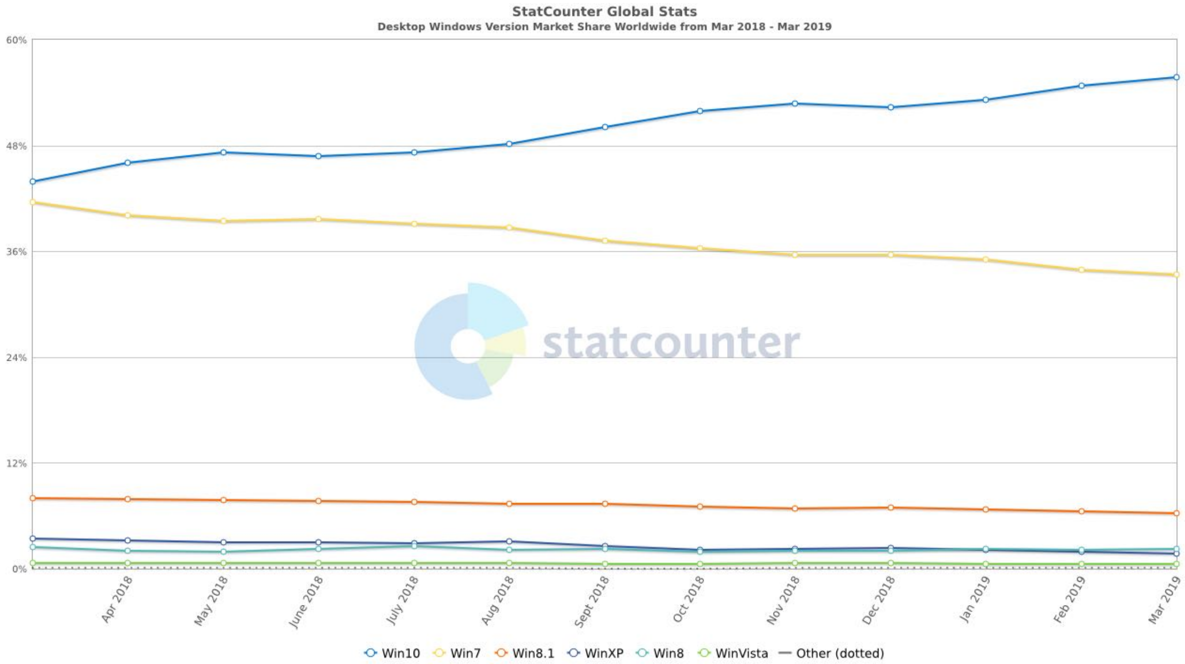


Figure 16 Windows OS Version Install Statistics (SCGS, 2019)

This does, however, pitch a case for the tight integration of software and hardware in a way best exemplified by Apple. By maintaining extremely tight control over both the production of their silicone and optimisation of the software to utilise it, they achieve some of the best performance, stability and general security within the industry. Reports state that this is the direction of their AV project currently as they have shed the automotive hardware function and are instead focusing on software and silicone (Clover, 2018).

Competitors instead are generally purchasing silicon being provided by chip makers such as Intel and NVIDIA. These companies have been working on AV processing hardware for some time now, with extremely optimistic roadmaps for reducing die size and increasing performance to match the technical needs of Level 4/5 vehicles (McGregor, 2017).

3.3.3 Conclusion

To conclude, the current trajectory for AV's would seem to result in an effective race to the bottom based upon the efficacy and safety of competing AV solutions. If not mitigated a 'winner' will be identified resulting in innovation and competition being hindered.

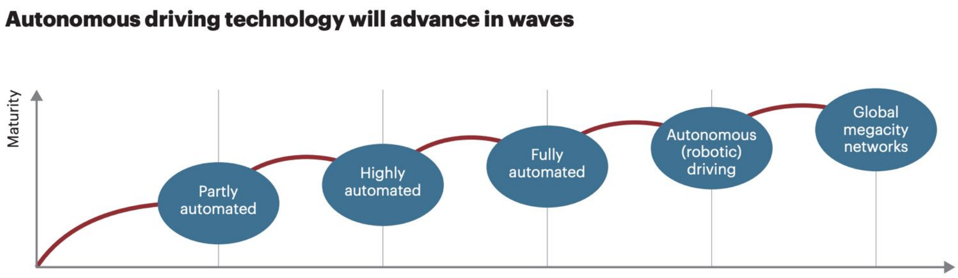
4. Autonomous Vehicles, a new direction? ‘the path to level X’

4.1 Introduction

This section will synthesise the concepts explored thus far, exploring the potential that could be realised from a branch in the direction of the current AV trajectory.

4.2 Reframing the Issue and Aligning the Opportunities

To be able to achieve the promises of mass AV adoption and overcome the hurdle of public acceptance there will need to be a dramatic pivot in the current direction of AV’s. From the analysis conducted it would be argued that the key frontier for this will be the gradual scaling and mass adoption within cities. This is contrary to the current trajectory, which sees L5 as the present direction, with eventual gradual V2X integration further down the line as can be seen in Figure 17 below:



	2015	2020	2025	2030	2035+
Legal protection	Scoring system for preventive driving	Daily legal protection for car rental and car-to-go	Legal protection based on mobile devices	Legal protection for all kinds of devices	Legal protection for all kinds of devices
Technology	First-generation automation and control	Second-generation automation, pooling	Third-generation fixed-distance automation	Fourth-generation automated traffic junctions	Fully automated traffic flow management
Infra-structure	Highway networks	Regional or national network	Selected megacities	Micro-/mobile city metropolises	Globally interconnected megacities
Standards	Internet standards for mobility apps	Camera and image processing and interfaces	Radio frequency and interface standards	Control and automation standards	Fully automated networks/ telematics

Figure 17 AV Technology Roadmap (Römer, Gaenzle & Weiss, 2016)

As mentioned within sections 2-3, the late integration of V2X within cities may not be a viable approach if AV's are to be successfully adopted. Therefore, enabling L4 and L5 vehicles with V2X will need to be realised far sooner. To differentiate such vehicles/infrastructure, an 'X' could be appended to their SAE level description resulting in L4X and L5X respectively, making it easy for consumers to understand their vehicles compatibility with a city/infrastructure.

Instead, to accomplish this, a story/vision needs to be defined for AV's and their interactions with cities, their respective infrastructure and populous. A fundamental debate is an argument between tailoring a city to its vehicular transport versus the rights of pedestrians and other road users (Sheller & Urry, 2000).

The proposition to be articulated is an exchange of traditional, inefficient and polluting means of transport, to be replaced by clean electric vehicles, which in situ are ready for autonomy. This could be aligned with green accords such as the Paris Climate Agreement or other national/global initiatives such as London's strict targets to reduce emissions (Blunden & Cecil, 2018).

A city could then scale this outward, banishing combustion vehicles from peak congestion zones, only permitting entry for those which are electric and satisfy the level of autonomy and connectivity required to enter the designated zone. Elements of this are already being instigated from an environmental perspective in London, as further charges are being applied to polluting vehicles in the congestion zone. Exemptions are only available for taxi's (not MaaS providers such as Uber) under the condition that "all new taxis must be zero-emission-capable petrol-electric hybrids" (Topham, 2019) which is already a step in the proposed direction.

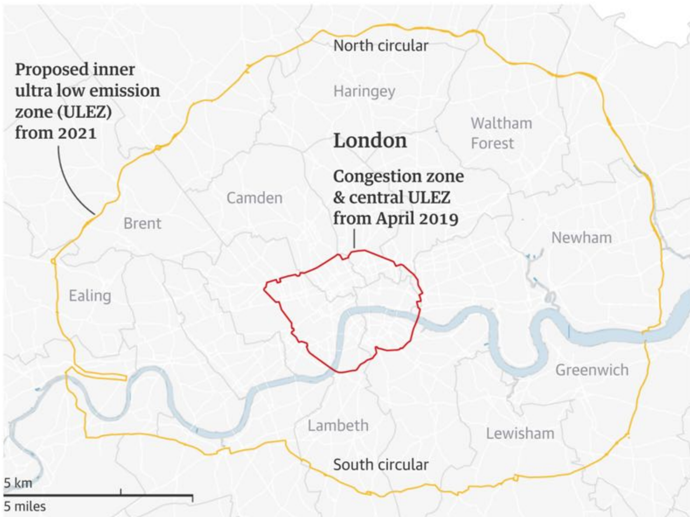


Figure 18 Map of Proposed London Emission Zones (Topham, 2019)

Tight integration would also allow for other benefits especially to localisation, as shared sensory data between vehicles and infrastructure coupled with central guidance/hive style processing could enable vehicles without a full L5 sensor stack that’s still extremely expensive and one of the critical inhibitors of successfully scaling AV's.

With such sharing, dependant on implementation, it is even possible that localisation devices could be retrofitted to eligible cars if they are a suitable platform, enabling them to leverage Level X infrastructure. This would not have to come at a detriment to safety either, as the connection to infrastructure coupled with the intelligent distribution of more advanced vehicles alongside utilisation of infrastructure could likely mitigate risk algorithmically to ensure that a defined level of safety is consistently met.

This would make the regulation and audit of a core system exponentially simpler while also enabling technologies such as ML and AI to further tackle traffic optimisation, however, based on a set of mathematical truths. This is something to which ML and AI are far better suited than the human-like interpretation and cognition that is required for success in L5.

This proposition should in principle be far more accessible than the current, relatively undefined, take on the rollout of the technology. It is essentially inevitable either way, but it seems irresponsible to hinder and elongate adoption purely for the technical challenge of L5 and distrust in governments to adopt infrastructure sufficiently. This would also tackle the societal issue identified in 2.6 as a neo-liberal approach to AV rollout needs to be avoided at all costs as the benefit and inclusivity to citizens needs to be accurately forecast and all but guaranteed, not just touted by AV companies and media in an attempt for public acceptance.

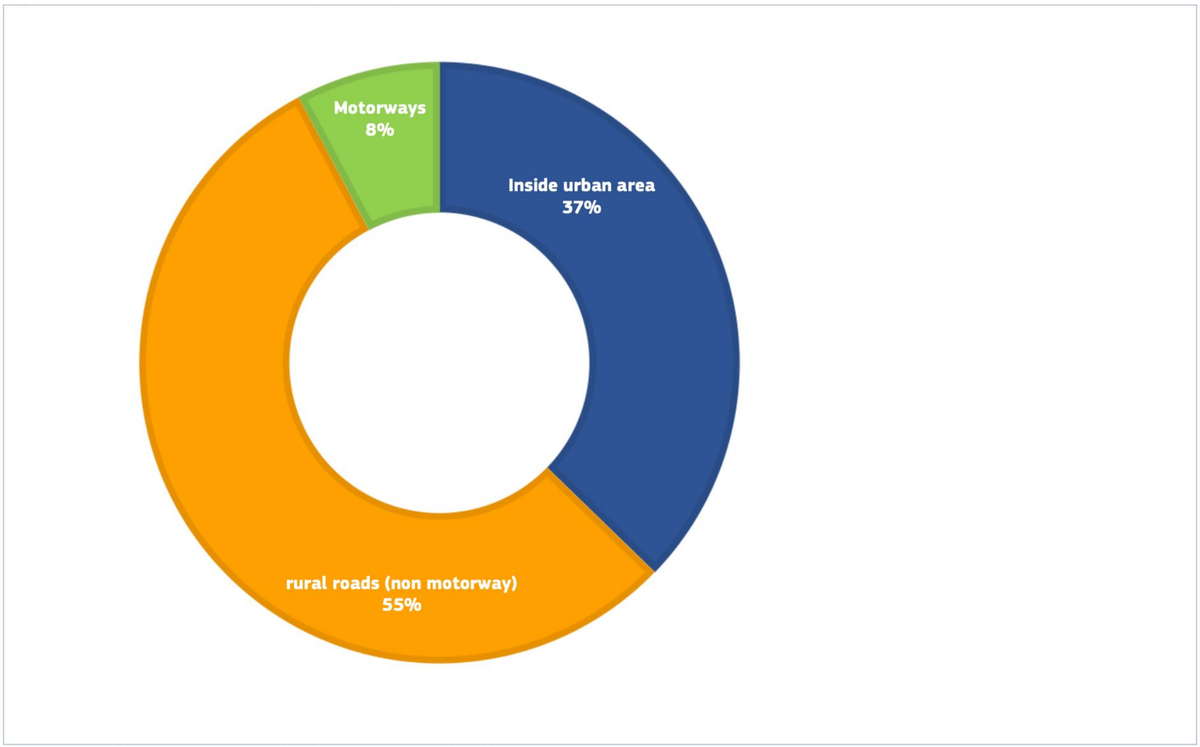
It would also overcome many of the points highlighted within earlier sections; especially tackling the public reception of AV technology. Generally speaking, city populations are already shifting away from ownership models towards MaaS due to the general pain of motoring and car ownership within cities. This provides the perfect test bed to demonstrate these technologies within a controlled environment where the actual benefits of AV’s can be demonstrated on both a statistical and emotional level. Something that AV companies are struggling with currently.

A pivot towards such integration would also create a massive new space for free-market innovation and capitalisation of hardware, software, goods and services. This would range from the production of the infrastructure to the development of integrations, governance software and a whole array of services within the new hyper-efficient market. It would also bring exponential benefit to other areas such as logistics and speed/access to mobility, which could have the potential to boost a city's economic standing significantly. Finally, a new business model of integrated mobility could provide consumers with the best combination of transport to get to their destination, incusing integration with public services where possible. Trials of this have already begun; however, generally there is still a "lack of integration, coordination, and effective governance among transportation regulators and providers between the city and the suburbs, and between public and private bodies" (Deloitte, 2019).

This direction aligns closely with one of the conclusive points from Deloitte's Mobility Index stating that "If cities continue to grow and the Organisation for Economic Co-operation and Development (OECD) predicts that 70 percent of the world's population will live in urban areas by 2050 15 —then public and private players need to find ways to move people and goods in ways that maximize use of space and minimize such social costs." (Dixon et al., 2019).

All of this is not to offset the development of L5, but instead to enrich it. All of the progress in this space will still be essential and can co-evolve with the actualisation of an optimised L4 city. It would likely still be the case that upon exit of a controlled zone, either the driver would re-take control or the L5 autonomous solution may complete the remainder of the journey. This could help soften the transition to AV's without entirely alienating the human workforce behind the mobility services of today.

The L4 city is simply a more sensible proposition for the successful early-stage adaption of this technology, and also for general societal good. This will also allow pure-play L5 competitors to focus on the remainder of the vehicular space, especially aspects such as rural areas where the most fatalities actually occur. At an early offset, this may not seem as profitable, which is likely why the present direction has been to become engrained within urban space, however, this is not what is best for the general advancement of mobility or society as a whole.



Source: CARE (EU road accidents database) or national publications
Last update: May 2017

Figure 19 Safe of Fatalities by Area Type within the EU (EU, 2017)

4.3 Environmental Design and Integration

To achieve the proposition above commitments would need to be made within environmental design and cross-integration standards.

A set of practices would need to be agreed either within an individual country/state or within a common market such as the EU. This would enable a broad base of competition to develop both vehicular and infrastructure-based solutions that would play into a newly formed competitive market place for fully integrated traffic management systems. These could then be combined to create cohesive rollout and adoption plans for cities in support of mobility and environmental targets.

The first city/government to implement such an approach if successful would demonstrate to the global mobility space what is possible with industry cohesion. Alongside this, it would create a temporary USP for the prospective city and its inhabitants, which will likely spur economic growth and prosperity.

As a result, this could also put forward the case for the standards defined to be further adapted and iterated globally. This would allow the individual components of the solutions to still vary from both a hardware and software perspective, however with the underlining points of connection and regulation being standardised making international collaboration, sales and also future education far simpler.

This could be contrasted to global internet standards such as mark-up languages like HTML and open-source libraries which are already managed highly efficiently and are core to our current digital prosperity.

Such an approach is once again in line with the Deloitte Mobility report which notes that for transport authorities “Adding more service or building more roads can be helpful, [however] developing better-integrated strategies with greater involvement from the private sector often yields better results.” (Dixon et al., 2019).

5. How to Achieve this? The 'Sim City' Proposition

5.1 Introduction

Sim City is a concept derived from the opportunities identified in Chapter 4. It is a further synthesis of the areas explored forming a practical proposition that could provide the framework needed for the pivot to city-first AV adoption and design. At the very least, such a proposition could resolve some of the outstanding concerns around regulation, verification and benchmarking within the industry.

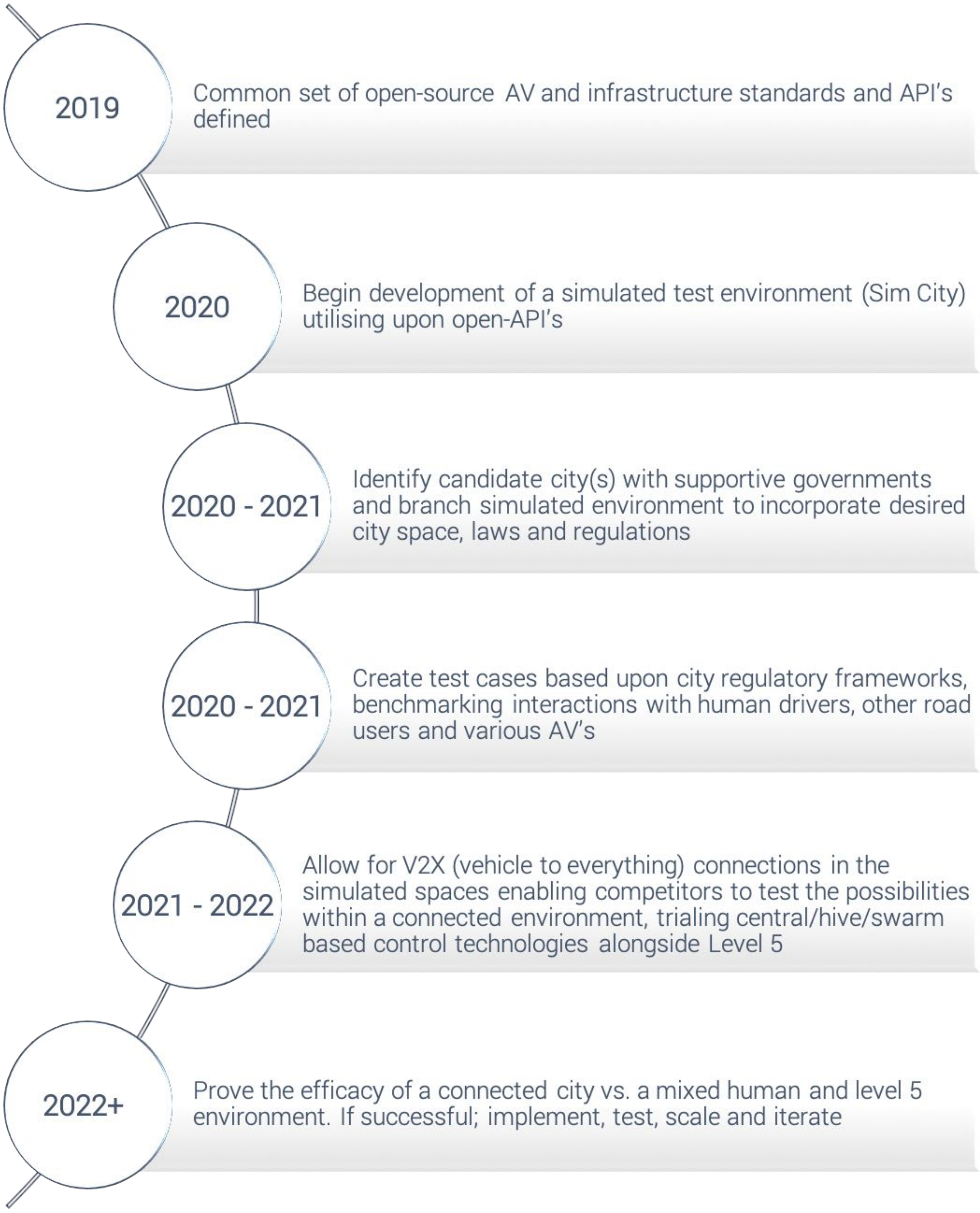
The base concept is a simulated environment similar to those utilised in much of AV testing today. The critical difference would be a base definition of open-API's that would be accessible to all, enabling integrations from various OEM and tech company solutions, with an initial goal of providing a benchmarking service to validate AV technologies. The test scenarios as with everything else would be open to all, with community and industry submissions welcomed.

If adopted, these benchmarks could be utilised for regulatory purposes and further tailored to suit the individual needs of various governments and transport authorities. This would allow for the open aggregation of crucial AV use cases and data while protecting the IP of participants. Therefore, benefits could be gained for all, reducing the amount of 'edge' cases which can have perilous consequences for L5 vehicles once adopted.

This all provides the ideal set up for the trial and implementation of V2X technologies which could be built into the simulated environment alongside further API's to form a catalogue of infrastructure and vehicular technologies. The end goal of this being to identify and demonstrate the optimisations that could be made within city transport by the actualisation of 'Level X' and the implementation of systems which can fully leverage the technologies available, thus enabling better efficiency resulting in a societal gain.

5.2 The Path to Sim City; Roadmap Proposal

This roadmap is an example designed to highlight the key milestones Sim City would need to set and achieve for AV's to gain a mass presence in cities in the near future based upon the contents of this dissertation. The dates are purely theoretical and have been set in line with current L5 developments, meaning that if developed, such a solution could be used to set the standards and regulatory framework for L4/L5 vehicle deployment and potential future 'Level X' integrated city propositions.



5.3 Solution Overview

The solution would essentially entail following the steps outlined in 5.2 by firstly defining a set of standards for an open API inside a simulated city environment that takes only the input of vehicle controls, and output's all available (simulated) environmental data such as LIDAR, GPS etc. thus creating a test bed for companies to benchmark and validate their autonomous solutions against competitors alongside an environment for regulators to produce some form of coherent regulatory standards for AV solutions to adhere to, essentially a digital driving test for autonomous solutions.

Not only could this be used for regulation, but it could also be used to simulate the interaction between different AV solutions, simulated traffic and potentially even examples of real traffic in an accurate fashion due to direct integration with various AV solutions and infrastructure standards.

Once developed and adopted it could begin to release additional information from V2I and V2V connections to the competitors developing AV solutions. Enabling competitors to study and demonstrate the maximum efficiencies to be gained through competitive V2X integration.

Alongside this, the co-development of a L4 system with the primary directive of optimisation could be compared, tested and proven, providing the business case for the need of such systems at a far earlier stage than is currently projected.

It would also enable governments to tailor connected infrastructure requirements and their respective costs towards a desired mobility solution and budget. The could even choose to fully maximise efficiency, removing as many constraints as possible to keep minimal infrastructure cost and higher efficiency, potentially even resulting in a revocation of standard road laws in the quest for the next revolution in the efficiency of urban transport.

5.4 Technical Feasibility

Nothing stated in the Sim City proposition is outside of the remit of the technologies we currently have available to us. In fact, it generally caters to the strengths of current technologies more so than current L4/L5 propositions.

This is in part because of greater environmental control coupled with the economies of scale that to be realised with the amount of situational data that could be aggregated, especially considering the immense complexity of a human-like L5 solution it may even be considered a more feasible proposition.

The simulation aspect is already commonplace; the main thing predominantly lacking is a set of unified standards. However, many competitors are already on the same platforms generally provided by SOC manufactures such as NVIDIA (Burke, 2019). This may prove to be advantageous; as a close understanding of the manufacturers software/hardware and simulation engines coupled with creating accessibility for alternative solutions and supporting infrastructure will forge a middle ground for innovation and regulation.

While there are still security concerns with such connectivity, the convergence insight could be the opportunity to tackle precisely such issues. With challenges already being explored within the industry, such as the NHTSA defining a priority for V2X communications within the 5.9Ghz spectrum and opening up to integration with technologies such as 5G (NHTSA, 2018).

With regards to an optimised Level X system, there are already strides in swarm robotics which may be transferable to the automotive space (Prakash et al., 2014).

5.5 Benefits to Innovation

As covered in 4.2 the pace of innovation and deployment of AV's that could be realised through integrated cities has the potential to accelerate the development of future mobility exponentially. As providing an open-source test bet which incorporates industry and regulatory standards would act as a catalyst for free-market innovation. Any competitors big or small could demonstrate their aptitude to compete in the space, with the benchmarks identifying areas for improvement and also providing a clear comparison to alternatives. Alongside this, the modularity of interchangeable smart infrastructure with a common interface API would create in essence a catalogue for smart infrastructure and city design. This could then either be utilised by city planners or specialist consultancies developing Level X city management solutions on behalf of Transport Authorities.

5.6 Regulatory Perspective

From a regulatory perspective, this could resolve the critical challenge of certifying Autonomous Vehicles. The requirements for a proposition similar to this have already been discussed within the industry, with Five AI's paper titled "Creating an industry-wide framework for safety" (Yu, 2018). This covers off comprehensively the benefits that could be gained and the requirements for such a solution.

5.7 Long-term Benefits

Aside from the obvious potential for rapid advancement in AV technologies and their adoption, there would be excellent potential for a massive reduction in the environmental impacts contributing to climate change and the public health issues that are currently present in cities.

From the perspective of governments who are set to lose massive revenues from vehicular taxes such as fuel and parking fines, effective taxation of transport based on CO_2 produced, contribution to congestion and time of travel could be enabled through an integrated city solution. As a result of this helping to resolve the conflict between investment in Level X infrastructure taking away from government monetisation.

There would also be the potential for cities to be intelligently built from the ground up, basing their infrastructure requirements on simulations and modelling allowing for them to find the sweet spot between cost/benefit. This could be especially useful in developing markets such as India and China.

5.8 Commercialisation

While the fundamentals of Sim City should be open-source and remain this way, there is no reason to not compete within the newly created field of Level X city traffic optimisation. With the best fundamental knowledge of the platform, this should provide any Sim City led solutions with a first mover advantage in the Level X space. This would not end in any form of monopoly, however, as there are many cities and the open testbed would allow competition within many markets.

As mentioned within the long-term benefits, there may also be the opportunity to integrate architectural tools into the solution, enabling the drafting of cities from the ground up with a tight focus on connected infrastructure. The scope of this could be indefinite, as an open platform could enable for the planning and integration of other transport infrastructure such as trains, trams, metro’s and pretty much any form of city transport/infrastructure imaginable.

6. Conclusion

To summarise, as articulated within this investigation there seems to be a clear industry trend towards full L5 autonomy. It seems that the extent of the implications of such a switch are yet to be fully defined or at very least seem to have been omitted until regulations are defined. This could be deemed as somewhat disingenuous; however, with the veracity of modern media resulting in the polarisation of most subjects due to click based monetisation, it is hard to find anyone at direct fault here.

The real shame is the lack of discussion both within the industry and supporting governments about open-source methods and general collaboration; because as articulated within the body of this text, without large scale cooperation any successful rollout of AV's will be in the distant future.

Only time will tell whether the current path to L5 will reach a level of public and regulatory acceptance to enable significant deployment within public space, however, if the neoliberal principles that are currently evident continue to prevail, whether a deployment will yield anywhere near the promised societal good is yet to be determined.

At best, we could get a significant improvement over the safety of human drivers. At worst initial deployments could fail with the potential for a detrimental impact on the progress of AV's.

If this were to happen it is possible that sentiment could still be recoverable via a proposal such as Sim City; however, there is also potential that it could result in regression from OEM's back to their incremental comfort zone, and simply be discarded by big tech. While these extremes are relatively unlikely, the current path would suggest that we will land somewhere between the two resulting in a delay of the technologies and their respective benefits.

If a significant pivot is not realised and mass city-based adoption does not come to fruition, then it is very likely that these technologies will not be entering our lives in any significant way for the next decade or two.

It is for this reason that collaboration is imperative in the AV space to prevent neoliberal tactics, arguably due to fiduciary duty, from big tech and potentially OEM's which could result in an AV rollout at the detriment of society.

By enabling an open testbed for collaboration, the true benefits of the technology can be realised within the AV space in situ with societal good. It would thereby enrich free market competition alongside supplementing it with transparent and auditable safety, standards and regulations.

This can be aligned with environmental and societal goals at the forefront of development, or at very least ensure that companies and lobbyist are not able to strong-arm governing bodies who frequently fall flat due to the complexities of technology regulation.

By creating the platform for an ethical yet profitable ecosystem, it is possible to appease the requirements for free-market capitalism and avert the potential detriment of an individualistic race to Level 5 autonomy. Alongside this correcting the current direction within the AV space, accelerating the progress of the technology and mobility as a whole in a positive direction, resulting in pace far above that currently projected.

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