Impact and benefits

1. The largest applications will be in the transportation of people and goods:
   a. Personal mobility-as-a-service (MaaS) delivered through a fleet, which may be heterogeneous in size, of autonomous electric vehicles as replacement for commuter and family cars
   b. Automating the driving of trains, trams, light railways, underground systems, taxis and buses
   c. Package delivery to the home or office

2. Benefits will be:
   a. 50-75% reduction in commuter road traffic in urban environments and halving of journey times, since vehicle occupancy can easily be increased to between 2 to 6
   b. Recovery of circa 460 hours per year per person (2 hours per working day) of time otherwise spent driving; individuals can be much more productive since vehicles will be equipped with broadband connectivity and charge points for tablets, phones and notebooks
   c. Substantial reduction in mobility expenses per person, estimated at £2,100 per person per year. That money was previously spent on (mainly) imported vehicles, imported fuel, parking charges, insurance and servicing.
   d. Subject to the technology, a reduction in accidents resulting in injury and death, since autonomous cars will not get distracted.
   e. Release of substantial car parking spaces in our towns and cities for better economic use
   f. Rapid switch-over from fossil fuel vehicles to all-electric vehicles, potentially assisting the UK in meeting Kyoto emission targets

Costs will be:
   a. There will be some winners and losers in the economic game, losers will include branded vehicle manufacturers supplying mass-market cars to the developed world (OEMs) and related component suppliers (tier 1s), body shop repair firms, downstream fossil fuel distributors, taxi companies
   b. Suitable vehicles might be assembled relatively quickly and cheaply by new ‘no-name’ OEMs, which could in theory be based anywhere: economics of battery technology supply, energy costs, labour costs, speed of product design, customizability of platforms, tariffs and other factors will determine winners and losers
   c. Insurance companies will continue to play a key role, but instead of actuarially determining the probability and cost of human cognitive failures giving rise to accidents, instead they will need to become expert in measuring the probabilities of artificial intelligence cognitive failures. That means they must build and become experts in highly sophisticated simulation environments of the world and be able to assess AI software against a very wide range of test
cases in that simulated world. Those who are slow and fail to develop this expertise will mis-price risk and ultimately fail.

3. Knowledge is being built in trials across the world, primarily in the US and Singapore. But it is straightforward to model traffic flows, impacts and economics. More difficult at this stage is assessing the point at which autonomous vehicles can be safely deployed in our complex urban environments since the quality of perception and planning systems depends on solving many unsolved problems in the fields of computer vision, behavioral prediction modeling and planning vehicle action in resulting entangled complex states.

4. No comment.

5. The global (and local) market opportunity, just on personal mobility alone, is huge. In 2015 the world manufactured and consumed around 87 million cars. McKinsey is one firm that has estimated the growth in the number of autonomous shared cars shipped by 2030, which they put at 10 million units that year, out of total shipments of 115 million by then. That would imply a global fleet of around 25 million autonomous cars by that date, but autonomous cars work much harder than owned cars, so they estimate autonomous cars could account for 32% of all journeys by that time.

Five AI believes this prediction is very conservative and the ramp will be much sooner and the numbers will be much bigger, more like 20 million autonomous unit sales by 2025 and a 40 million autonomous vehicle global fleet by that date.

If correct, this global fleet could offer capacity of 200 million seats. Assuming an average seat utilization of 50%, and 12 billable journeys a day per utilized seat, that would equate to 1.2 billion billable journeys each day. Assuming journeys would be priced the same as a bus ride (£4) the service opportunity alone equates to a £1,400 billion annual TAM. Our modeling suggests an operator gross margin of 25% is achievable at these fare levels, assuming appropriate levels of vehicle, insurance, cleaning, maintenance and energy input costs.

The supplies of those inputs also represent very significant global market opportunities themselves, aggregating to an estimated £1,050 billion. That figure includes:

- Vehicles: £400 billion
- Sensors and computational hardware platforms: £200 billion
- Software licenses and on-going support: £370 billion
- Insurance: £50 billion
- Energy: £100 billion
- Cloud/app IT services: £40 billion
- Support services (monitoring, maintenance, cleaning): £220 billion

Creating an Enabling Environment
6. The UK is not (yet) a leader in autonomous vehicle technology development, despite the fact we have some of the top university research departments in the fundamental sciences of visual geometry, deep learning, artificial intelligence and control systems. In fact there are two serious attempts in the UK to build global players that can leverage these raw capabilities – Five AI and Oxbotica. Both are tapping into key academic knowhow at the University of Oxford and to a lesser extent, Cambridge, Imperial and UCL.

Demonstration facilities are not really the issue, although a simulation and physical test track would have significant value for all developers.

7. US companies lead the field today, substantially because of DARPA funding in the mid-2000s and the Grand and Urban challenges they set and funded. All leading spin-outs from US universities that went on to create software companies for driverless cars were participants in the DARPA challenges – Berkeley’s team which became 510 Systems which was then acquired by Google to form the platform for their driverless car program, Carnegie-Mellon’s team now working for several companies most notably Uber, Stanford’s team now working for drive.ai, MIT’s team now working for Nutonomy, being examples.

Of course, the availability of huge pools of capital in technology companies – Google, Apple, Uber – and their ability to recruit and retain some of the world’s top talent in the fields of computer vision and machine learning due to this capital and the research-led working environments they created, represents a serious challenge to counter in the UK.

And US venture capital firms are more technologically-aware than their European counterparts and have access to larger pools of capital themselves – endowments and fund-of-funds – due to their better track records. That weight of capital outside the tech firms themselves also represents a challenge for companies in the UK taking on this challenge.

The UK government initiative to support driverless car technology development, especially the learning from the DARPA challenges, is exactly the right move to stimulate activity and focus in this area and should be applauded.

Beyond that, UK startups need to counter the gravitational pull of talent to large US technology firms by offering competitive salaries, significant stock options and greater access to resources beyond their existing reach. Much of that comes down to the caliber, experience and energy of the leaders of these companies and their investors, but the one role UK government should consider beyond the CCAV funding challenges would be the foundation of a specific venture firm operating in the UK market to invest alongside existing UK firms but with a remit to support this segment. Such a firm should seek to attract top venture investor talent from the most prominent and successful technology venture firms operating in London – for example Accel, Index, Balderton, Atomico and some of the smaller deep tech investing firms, such as Amadeus, Mosaic, Notion and Kindred.
Beyond that, we are in the realm of industrial strategy and the politics of whether it is a good idea or not for governments to own or control businesses in emerging fields. In general, this has not worked well for Anglosphere companies, although there is more sign of success in some continental European countries, notably France.

8. CCAV has been extremely effective. An almost perfect start. Team is sensible, commercial and ambitious. We don’t yet have any comment on Innovate UK.

9. The environment is enabling, with the first round of CCAV funding spread across a range of projects, clearly taking a somewhat experimental approach to begin with. In retrospect, possibly too much funding was offered to very small companies on peripheral areas of industrial research.

What is needed now, and CCAV recognizes, is to put more wood behind fewer larger arrows. The CCAV2 stream 1 large-scale challenge is an important step to take, since it should help enable UK firms to catch-up with and eventually overtake US (and German, Japanese, Swedish, Chinese) counterparts. That catch-up is possible because the science underpinning many of the necessary features is evolving quickly, and in our Universities, so intercepting that science now is advantageous compared to intercepting it in 2010, say.

10. Eventually, we will want to layer V2X (vehicle to infrastructure) communications over the cognitive capabilities of the vehicle itself, to further reduce accident rates and aid in planning. The specific technology to achieve this is being debated globally. But it is not essential to the launch and development of driverless cars. We humans do not have (or need) ubiquitous communications. And any systems that were to rely on the availability of such a communications network alone would be intrinsically unsafe.

We’d judge that for the time being existing physical infrastructure suitable for human drivers would be suitable for driverless cars too. In time, we may all agree improvements that would make recognition of road markings, signs, signals etc clearer but this should not be a factor for deployment in the next 5 years or so.

11. We see deployment in four phases:
   a. Operation of a shared driverless car service across fixed routes in/out of an urban environment (eg suburb to city centre); those fixed routes are regulated and insured one-by-one, based on simulation, supervised operation and then insurance underwriting
   b. These routes cross at nodes and any vehicle can then convey passengers from any point to any point on an approved, insured part of that network – almost city-wide mobility but not quite
   c. Last mile can be added from home to route and from route to office; now vehicles can transport people up door-to-door
   d. Cities will then remove exclusions making every route available

12. No comment yet.
13. Yes, but others will be able to provide better comment than Five AI.

14. We think that to the extent the technology requires cognitive decision-making involving life or death situations, it should obey some important principles, for example:
   a. All human life is equal (so children worth the same as adults, pedestrians worth the same as passengers)
   b. Systems should measure and assure they do not get into a situation where decisions must be taken between options, all of which involve the risk of serious injury or death. Therefore measuring the extent to which this is achieved in all sorts of complex entangled situations in simulation will be an important ethical objective in the design of the software.

15. We need a legal framework that permits fully autonomous vehicles to operate on our streets without local on-board supervision and without being restricted to certain roads, speeds or behaviors. We need optionality on who takes the liability risk on accidents; one option should be that the liability can be taken by an insurer. That is needed since in a MaaS world, the vehicles could be supplied by a no-name company (man of straw) and another small firm could provide the software.

16. In the emerging fields of computer vision, machine learning, artificial intelligence, the University outputs of our top schools is as strong as anywhere in the world. Our challenge as a country is to keep those people in the country and to configure them into world-beating companies.

17. We think the strategy and work is wide enough.

18. We are seriously concerned that our universities will find it harder to attract talent to study for first and second degrees in the UK, due to the mood music change alongside Brexit. We are concerned that strong students will feel discouraged from remaining in the UK and contributing to companies here and that the visa process which is likely to be introduced will form an unnecessary and symbolic barrier that it would be best not to have. Vias-free travel and right to work for relevant people would be good. Since Europe’s car industry is centered in Germany, the fact the UK is leaving the EU may also alter the level of trust that partners and customers for our technology are looking for. They may feel more aligned with German, French, Italian or Swedish companies. Membership of the EEA or equivalent could help.

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