TRAFFIC FORECASTING AND AUTONOMOUS VEHICLES

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1. INTRODUCTION

We are often asked to forecast traffic (and sometimes concession revenues) or travel demand 20 or 30 years into the future. Delivering a reasonably accurate forecast is an important component to estimate the feasibility of a particular project or the viability of a comprehensive transport plan. In most cities, the benefits of the plan or project will depend on an estimate of travel times on alternative modes (where relevant), routes and modal shares. We have been doing this for many years (with variable accuracy) under a broad assumption of "business as usual"; that is travel trends, capacities and mode preferences (defined by the parameters in our models) will be retained into the future.

Over the last couple of years we have learnt this this is unlikely to be the case. Several trends that were weak in the past are becoming increasingly significant: "peak car", very variable fuel prices, internet shopping, distant presence. The most disruptive of these is likely to be the introduction of Autonomous Vehicles (AV) or self driving cars.

It is expected that autonomous vehicles will have a number of impacts in the near future including:

- Reduction of accidents and therefore reduced number of incidents and improvements on travel time reliability;
- Increases in road capacity, and possibly changes in speeds, with no investment in infrastructure; the impact will be different depending on the road type and context;
- Trip induction, at least because some people unable to drive today will be able to use them in the future; this will also depend on whether they are rented or owned and how they are used;
- Disruption to the concept of value of in-vehicle time as the time will no longer be wasted.

- Potential negative impact on public transport, in particular low frequency services

The paper is organised as follows. The next section identifies 12 key questions that are critical to how we would account for AVs in our models and projections. Section 3 describes a Delphi exercise organised by the authors to gather views on these questions. Section 4 describes the results achieved after two rounds of Delphi questionnaires. Finally, Section 5 outlines some suggestions on how best to represent the impact of AVs on our models.

2. KEY QUESTIONS

The central question we are trying to address is how to incorporate, in our models and long terms forecasts, the possible impact of AVs. As the type of AV that is most likely to be disruptive is the full self-driving vehicle we focus only on those defined as Level 4/5, that is vehicles that can drive themselves without a driver/passenger on board. Other levels of automation will certainly contribute to reduce incidents on motorways, for example adaptive cruise control, and some are already deployed; these are not the focus of this paper.

To get a better handle on estimating the impacts that introduction of AVs would have from modelling and forecasting purposes we set up a Delhi exercise (see section 3 for details). We identified an original set of 10 questions for the first Delphi round (Round 1). Learning from the responses to this first round we adapted the questions and their number was increased to 12 for Round 2. The questions are organised to identify when AVs will be available, when they will be a relevant share of the fleet and of traffic (these are different), what proportion will be rented and which owned by individuals, how much would they cost to own and rent, the impact they will have on capacities and on other modes of transport. The 12 questions are as follows:

1. What year do you estimate AVs will be available for purchase by ordinary citizens in your country/region? This is a key date that may be seen as the start of the introduction of AVs although their initial impact would be small.

2. What year do you estimate AVs will constitute 10% and 20% of the car fleet in your country/region? These dates are more important than the previous one as we can expect the impact of AVs to be more significant as they increase their share of the car fleet.

3. What would be the premium (in US$) to be paid on purchasing an AV compared to a normal car? An important question that would influence the adoption speed for AVs.

4. What proportion of the AV fleet will be owned by individuals whilst the rest is available for hire by the minute or with an Uber style pricing? This is a very difficult and also a very critical question. Owned AVs and hired AVs can be expected to be used in different ways and generate different impacts. The current take up rate for car clubs (e.g. Zipcars) is limited but there are many reasons why AVs for hire will be more like Uber/Lyft.

5. For rental AVs, how do you expect the pricing to be set compared to Uber? Present it as a ratio over Uber pricing (ignore surges). AVs for hire will not need to cover the costs of the driver but will incur in other costs for a more expensive vehicle, stabling and perhaps more rigorous maintenance standards. If the balance is cheaper than Uber today then the impact would be greater.

6a and b. What do you expect will be the impact on the capacity of freeways/motorways (no at grade junctions) when a specific proportion of total traffic is AVs (10% and 20% of the traffic)? It has been argued that AVs, even as a small share of the traffic, will improve capacities because they will dampen and even stop shock waves. This impact would be different in motorways compared to urban roads. This influence is something we could introduce in our models today.

7a and b. What do you expect will be the impact on the capacity of urban roads (with traffic lights and roundabouts) when a specific proportion of total traffic is AVs (10% and 20%)? In questions 6 and 7 the impacts is presented as a ratio over current per lane capacity in pcu/lane/hr.

8a and b. What do you expect to be the effect on trip making for AV owners and renters after five years of AVs becoming available? Present this as a ratio over current average vehicle kilometres travelled (VKT) per person per year. Here we try to get a better idea of the issue of induction. AVs will have new users: those unable to drive today. For those owning an AV they may opt for sticking to one car (instead of two) and exploit the greater flexibility of AVs to run independent errands while at work. Those abandoning car ownership to hire AVs may find that sometimes using public transport may be cheaper and faster.

9a and b. What do you expect to be the impact on Urban bus Public Transport demand when AVs are 10% or 20% of the car fleet? A critical question as one can expect normal buses, in particular low frequency services, to be more vulnerable to the added attraction of a self driving vehicle on demand.

10a and b. What do you expect to be the impact on Urban Fixed Track Public (Rail, metro, LRT, BRT) demand when AVs are 10% or 20% of the car fleet? AVs may be ideal feeder services to fixed track public transport on segregated right of way; or a significant competitor that takes away demand. As fixed track systems are only introduced where there is high demand hence the higher frequency implied might be a good defence of their market share.

11a,b and c. What would be the effect on the behavioural (for demand modelling) Value of Travel Time Savings (VTTS) on the part of AV users, given that they can legally undertake other activities while travelling in them. Express the effect as a ratio over the behavioural VTTS when driving a conventional car? Currently we can legally talk to a fellow passenger, listen to music or educational recordings and in some countries have a hands-free telephone conversation and even smoke. AVs will offer opportunities for additional activities like working on a laptop, reading reports and even having a nap if required. Time spent on an AV will not longer be wasted and this will affect the behavioural value of time. Again, this is something we could introduce in our forecasting models to better reflect the impact of autonomous vehicles.

12a,b and c. What would be the effect on the Social Value of Time to be assigned to AV traveller (given that they can legally undertake other activities while travelling in them) in Cost Benefit Analysis. Express the effect as a ratio over the Social VTTS when driving a conventional car? This is not a modelling question but one pertaining to project appraisal; however, as transport specialists we may have a view on what would be the most appropriate way to consider time saved by AV passengers compared to time saved by user of conventional cars, public transport or other modes.

3. THE DELPHI POLL

The authors have been using simple approximations when trying to forecast for transport projects beyond 2025; these were mostly modest increases in road capacity at around 2025-2030. We realised this was insufficient and decided to gather the views of a wider range of experts in a Delphi poll was the best approach.

The Delphi method is a structured communication technique developed as a systematic, interactive forecasting method which relies on a panel of experts. Delphi is based on the principle that forecasts (or decisions) from a structured group of individuals are more accurate than those from unstructured groups (https://en.wikipedia.org/wiki/Delphi_method).

We used the Transport and Traffic Modelling Group in LinkedIn as a platform to launch a Delphi exercise. A total of 45 modelling experts took part, all of them with at least 10 years of experience post studies; some were selected from the LinkedIn Group and other invited directly by the authors. Ten of them were well know academics, 9 worked in government agencies and the rest worked in the private sector in different roles, mostly as consultants. They were grouped in 5 regions, the USA & Canada, Western Europe, Australasia, Latin America and the Rest of the World (RoW):

	Number of participants	Average Years of Experience
USA & Canada	10	24
Western Europe	13	24
Latin America	8	23
Australasia	7	24
RoW	7	20
Total	**45**	**23**

4. RESULTS

4.1. General

We present here the results from the second and last round of this Delphi. The main objective of this Delphi was to gather views on the best way to approach transport and traffic forecasting for a future with Autonomous Vehicles (AV) level 4/5 (that is they can operate without a passenger/driver) in circulation. There is no assumption about interconnected vehicles or a particular level of intelligence in the infrastructure.

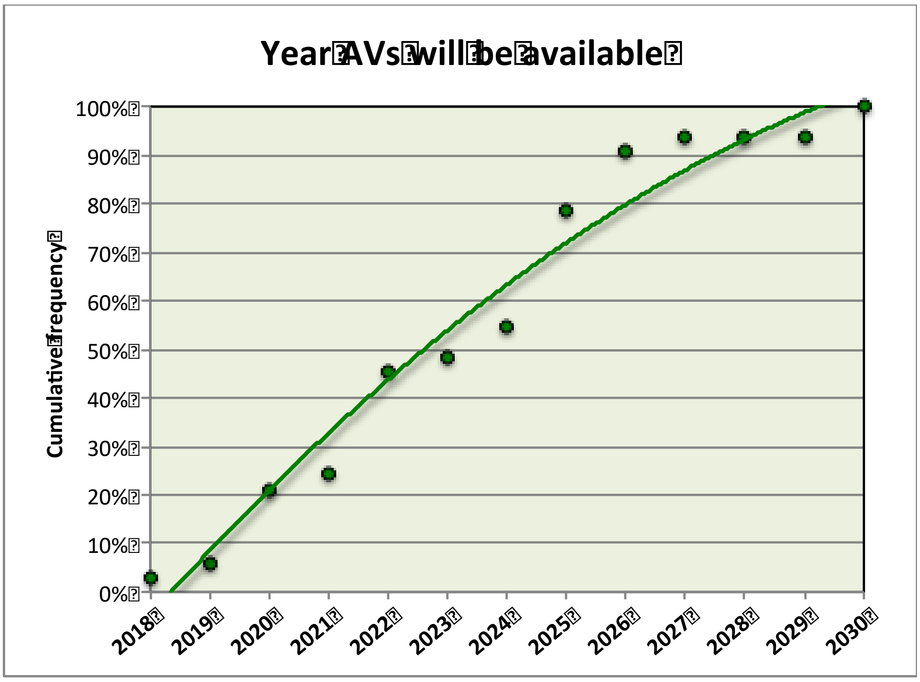
Overall, there is more dispersion than consensus of views reflecting our limited understanding of how the future will pan out when it comes to AVs. Table below shows a numerical summary of all responses. One should not adopt at face value the mean response as an “average forecast” because the impact of AVs will depend significantly on the context.

	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
	World		US & Canada		Western Europe		Latin America		Australasia		R o W	
1. Year AVs will be available	**2023**	2.9	**2021**	2.0	**2025**	2.7	**2026**	0.6	**2024**	1.8	**2025**	3.6
2a. AVs will be 10% of the car fleet	**2032**	7.0	**2028**	5.1	**2033**	5.7	**2039**	14.4	**2032**	2.1	**2029**	4.2
2b. AVs will be 20% of the car fleet	**2037**	8.5	**2033**	6.2	**2039**	8.0	**2045**	17.1	**2037**	2.1	**2035**	6.0
3. Premium to be paid for an AV	**$6,677**	$3,816	**$5,111**	$3,361	**$7,000**	$3,338	**$7,000**	$2,449	**$5,600**	$2,881	**$9,800**	$5,263
4. Percentage of AVs owned %	**42**	29	**45**	29	**33**	21	**56**	39	**47**	32	**37**	36
5. Ratio AV_price/Uber_price	**0.9**	0.3	**0.7**	0.3	**0.9**	0.3	**1.0**	0.1	**0.9**	0.1	**1.3**	0.5
6a. Ratio Freeway Lane Capacity @ 10%AV	**1.0**	0.1	**1.1**	0.1	**1.0**	0.1	**1.0**	0.1	**1.0**	0.0	**1.0**	0.1
6b. Ratio Freeway Lane Capacity @ 20%AV	**1.1**	0.1	**1.2**	0.2	**1.1**	0.1	**1.0**	0.2	**1.1**	0.0	**1.0**	0.2
7a. Ratio Urban Lane Capacity @ 10%AV	**1.0**	0.1	**1.1**	0.1	**1.0**	0.1	**1.0**	0.1	**1.0**	0.0	**0.9**	0.2
7b. Ratio Urban Lane Capacity @ 20%	**1.0**	0.2	**1.1**	0.1	**1.1**	0.1	**1.0**	0.2	**1.0**	0.0	**0.9**	0.2
8a. Ratio AV Owners VKT/Car owner	**1.1**	0.3	**1.1**	0.1	**1.2**	0.1	**1.0**	0.2	**1.1**	0.1	**1.0**	0.4
8b. Additional percentage of AV_VKT	**12**	17	**9**	6	**10**	14	**3**	5	**19**	21	**26**	36
8c. Ratio AV Renter VKT/Car owner	**0.9**	0.3	**0.9**	0.2	**0.9**	0.4	**0.8**	0.4	**1.0**	0.0	**0.9**	0.2
8d. Additional percentage of AV_VKT	**13**	10	**18**	11	**13**	10	**6**	10	**12**	6	**11**	13
9a. Ratio of Bus demand @10% Avs	**0.9**	0.2	**0.7**	0.4	**1.0**	0.1	**1.0**	0.0	**1.0**	0.0	**1.0**	0.0
9b. Ratio of Bus demand @ 20% Avs	**0.9**	0.2	**0.7**	0.3	**0.9**	0.1	**1.0**	0.0	**0.9**	0.1	**1.0**	0.1
10a. Ratio of Fixed Track PT demand @10%	**0.9**	0.3	**0.8**	0.4	**0.9**	0.3	**1.0**	0.0	**1.0**	0.0	**1.0**	0.0
10b. Ratio of Fixed Track PT demand @20%	**0.9**	0.2	**0.9**	0.3	**0.9**	0.3	**1.0**	0.0	**0.9**	0.1	**1.0**	0.0
11a. Journey to Work: ratio AV_VTTS	**0.9**	0.2	**0.8**	0.2	**0.9**	0.3	**0.8**	0.2	**0.8**	0.1	**1.0**	0.2
11b. Journeys during work: ratio AV_VTTS	**0.9**	0.2	**0.9**	0.2	**0.9**	0.3	**0.9**	0.3	**0.8**	0.1	**1.0**	0.1
11c. Other journeys: ratio AV_VTTS	**0.9**	0.3	**0.8**	0.2	**1.0**	0.4	**0.9**	0.1	**0.8**	0.2	**1.0**	0.1
12a. Journey to Work ratio Social AV_VTTS	**0.9**	0.2	**0.9**	0.3	**1.0**	0.2	**0.9**	0.2	**0.9**	0.1	**1.0**	0.1
12b. Journeys during work: ratio Social AV_VTTS	**0.9**	0.2	**0.9**	0.2	**0.9**	0.2	**0.8**	0.3	**0.9**	0.1	**0.9**	0.1
12c. Other journeys: ratio Social AV_VTTS	**0.9**	0.1	**0.9**	0.2	**0.9**	0.1	**0.9**	0.2	**0.9**	0.1	**1.0**	0.1

We now look at some of the key questions in greater detail. The graphs and comments do not distinguish different regions. In commenting on the results we are also guided by the narrative some respondents provided to their own answers.

4.2. When will AVs be available

The mean for all regions is 2023 but the US and Canada expects them to be available by 2021, incidentally a year earlier than in Round 1. Europe continues to be more pessimistic (average 2025) and Latin America expects them even a year later. The following chart shows the cumulative distribution of answers to that question.

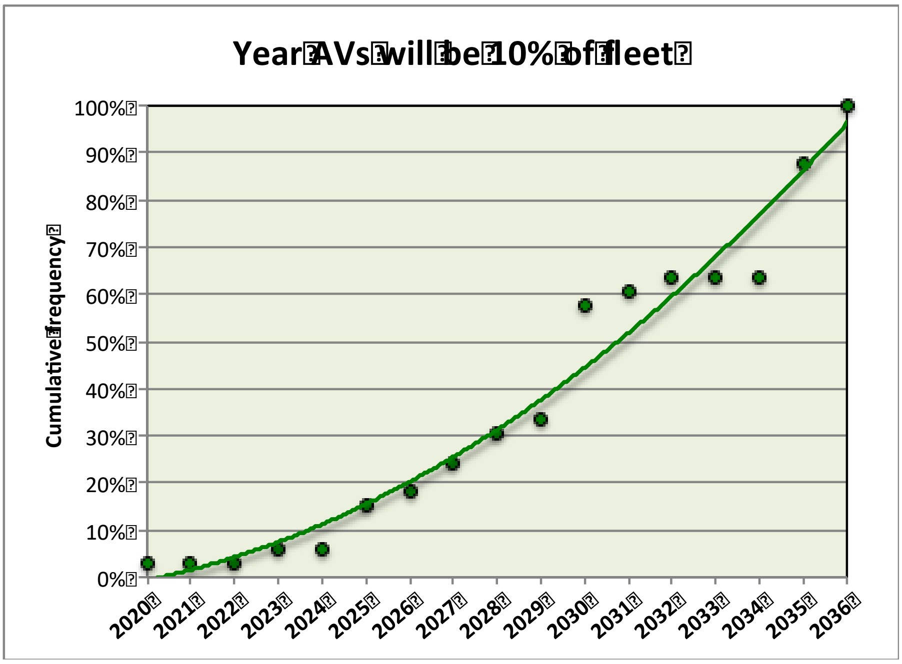


It seems fair to accept that, for the purpose of travel forecasting, AVs will be available by 2026 at the latest. Effective availability, and more importantly the date when AVs will be 20% or more of the fleet, will vary from country to country.

4.3. AVs as 10% of the fleet

This question is also related to the rate of growth in car ownership in a region and to the rate at which cars are scrapped either because of age, accident or export.

The mean response for the 10% threshold was 2032 but with a large dispersion. North America expects this to be achieved 7 years after AVs are available; the expected lag in Europe is 8 years but in Latin America is 13 years. The Rest of the World, heavily influenced by Asia, seem to expect to reach this 10% faster: 4 years after AV availability.



As can be seen, those who expected early availability also expect AVs to reach 10% of the fleet earlier, even as soon as 2020. This reflects different views on how attractive AVs will be, and the role of mobility companies like Uber in adopting the technology and replacing drivers 'en masse'.

This seems to be a fair comment as companies like Uber have significant influence on the purchase of new vehicles and can increase the AV share of the fleet very rapidly. On the other hand, Uber like firms are not successful everywhere and are absent in many areas. This suggests that there will be differences in the rate of AV penetration not only amongst countries but also within them; it has been suggested that in world cities like New York, San Francisco, London, Paris and Hong Kong, AVs will reach these thresholds faster than in other locations.

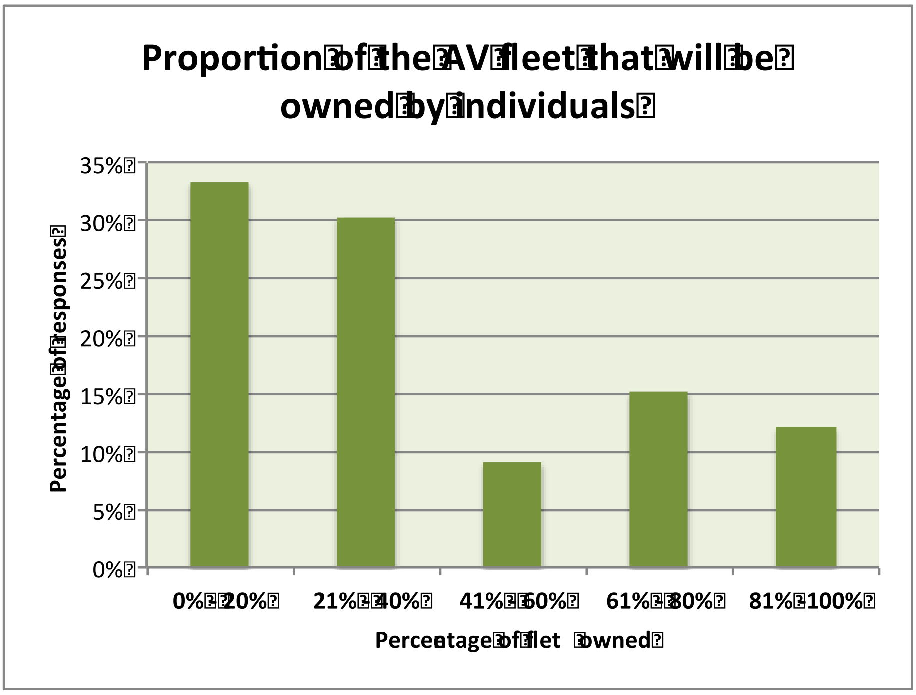
4.4. Rented or owned?

During Round 2 of this Delphi, Uber announced it intends to offer Volvo AVs to a sample of users this year in order to test the technology. It is likely that the Uber model will prevail and that this will make the rental of AVs much simpler and more attractive.

On average, respondents estimated that 42% of AVs would be owned. Latin Americans seem to be more attached to owning a vehicle and their average expectation is 56%. Western Europeans are in the other extreme, perhaps because they are used to better public transport, with only 33% of ownership estimated there.

Overall, more than 60% of the answers stated that the majority of the AV fleet will be available for rent. Indeed, companies like Uber and Lyft are extremely well placed to exploit this technology with their experience to manage fleets and direct vehicles to areas of greater demand at any one time.

One possible interpretation of the figure below is that respondents are split between those that love their cars and driving, and those who care only about mobility as a service, be it public transport or Autonomous Vehicles; emotions influence strongly our views of the future.

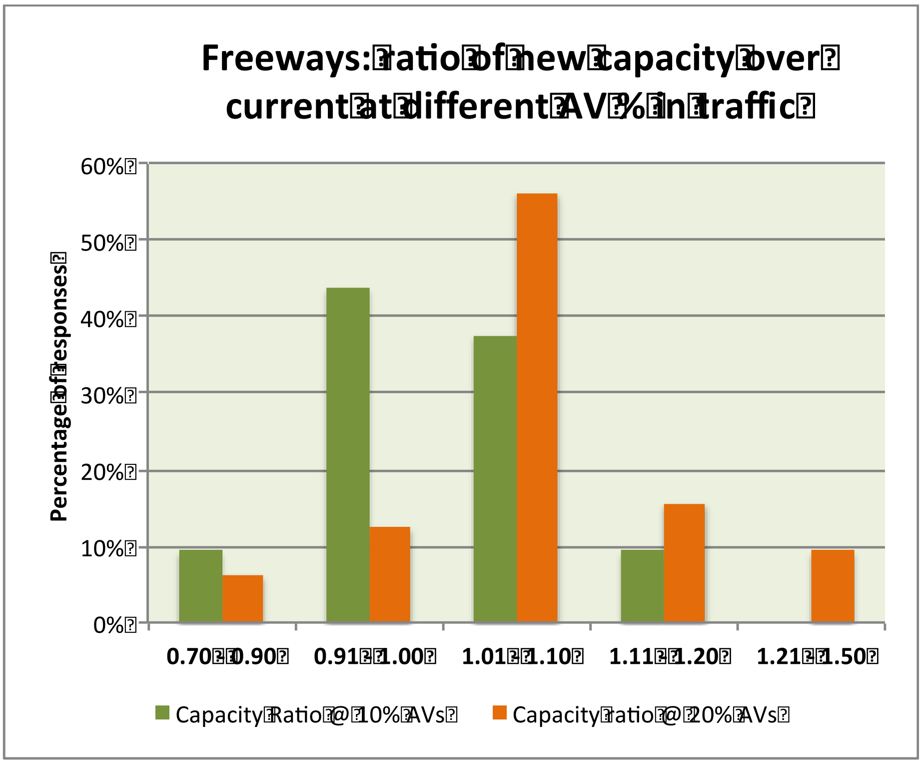


4.5. Impact on capacities

This question is posed when AVs are 10% and 20% of the traffic and this is likely be reached with AVs being less than 10% or 20% of the fleet. For simplicity, we assume this 10% applies to the peak, when capacity is a limiting factor.

Several respondents argued that at low traffic penetration for AVs the impact on capacity would be minimal or even negative, as they would only drive legally. North Americans are more optimistic about a beneficial effect on capacity.

The mean view is that at least a 10% improvement in capacity will be achieved when AVs are 20% of the traffic. There are, of course, extremes. Some believe that the impact on freeway capacity will be large; this is in line with the argument that even a small proportion of AVs will be able to smooth traffic, prevent shockwaves and therefore improve capacities significantly.

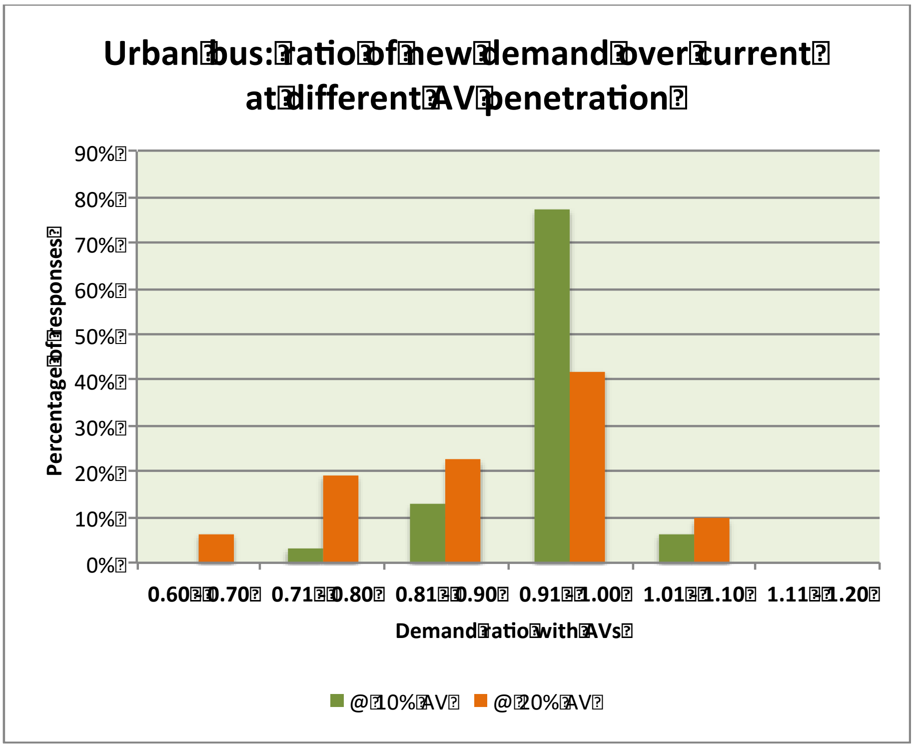


It is generally agreed that the impact on urban roads will be less significant and probably neutral, even at 20% of the traffic.

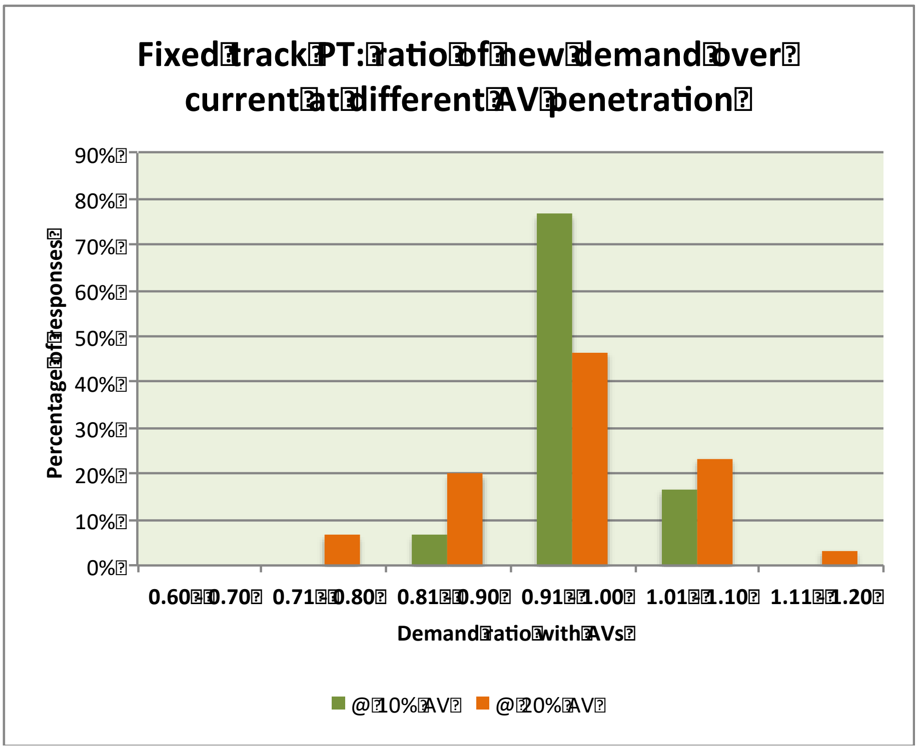
4.6. Impact on Public Transport

Overall the average expectation is a drop in bus demand of around 10% (for AVs at 10% fleet penetration) with a marginally greater one for 20% AV penetration. These figures hide regional variations. In the US & Canada the reduction is closer to 30% where in the rest of the world (including ROW) the decline in demand is minimal, perhaps reflecting greater public transport mode share, coverage and frequency.

Some respondents expect AVs to contribute to bus demand. It is argued that the use of rented AVs will reduce car ownership and therefore there will be many situations in which a bus will be almost as good as an AV and possibly cheaper. This argument, of course, is city dependent and even where in the city one resides. We believe that low-frequency bus routes will suffer most as they are easily replaced by AVs. Therefore, it will be important to adapt these results to each local context.



There is an agreement that fixed track, with protected right of way, will suffer a smaller reduction in demand than buses. Fixed track systems also seem to fit better with AVs as feeder modes, now that no large Park & Ride parking spaces are required. This explains why some respondents expected fixed track services to gain demand with AVs.

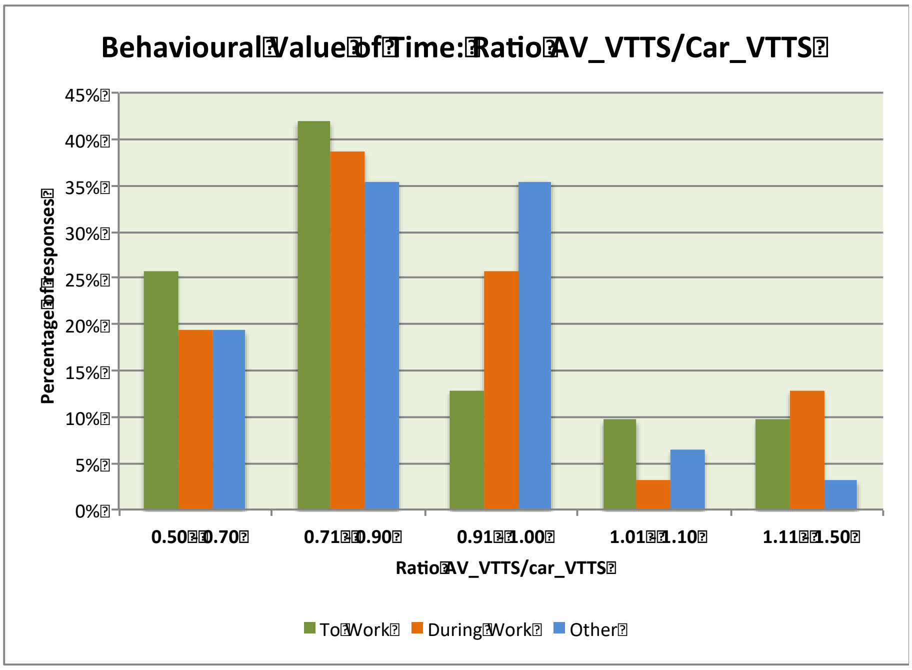


There remain many unknowns in establishing a sensible expectation for the impact of AVs on public transport.

4.7. Subjective Values of Time

The prevalent view from the respondents seem to be that there will be a 10% or so reduction in the behavioural Value of Travel Time Savings (VTTS), that is the parameter in the utility function or generalised cost that multiplies travel time. We consider this reasonable.

There is, however, a wide dispersion in the responses that makes us doubt everyone interpreted the question in the same way. As shown in the chart, a non-trivial number of respondents believe that the VTTS will increase when travelling on an AV. Although the impacts on different journey purposes vary, it is difficult to identify a consistent pattern in these variations.



Some respondents were quite aggressive assuming that the VTTS could be even halved under AV operation; this is not our view. For those who consider that the Value of Travel Time Savings could not possibly increase when using an Autonomous Vehicle the average value the ratio is about 0.80 (calculated by ignoring values above 1.0) for all the journey purposes.

Overall, the impact on the Social (or Equity) Value of Time is suggested to change in line with the Subjective VTTS.

5. CONCLUSIONS

An immediate reaction to this Delphi is that there is a wide spread of views on when and how will AVs impact on current travel conditions. This can be interpreted as lack of knowledge, or at least lack of consensus, on these impacts. This is not the case of “we did not see it coming” as was the case with smartphones, Uber and Airbnb. We do know it is coming but we find it very difficult to estimate how they will be used and how they will affect mobility as a whole.

A tempting but irresponsible reaction to “how little we know about the future of AVs” is to be complacent, assume nothing and gloss over their possible impact. On the contrary, we now know that they will be available within the next 4-10 years and that they will influence most aspects of travel and mobility. Autonomous Vehicles will be a very disruptive technology not only in the mobility arena but also in many other fields like insurance, car parts and repairs and even potentially urban form. It will be negligent to ignore their potential impacts, even if uncertain, in our forecasts.

We suggest it will also be wrong to take a single estimate of the impact of AVs as the most likely future.

What this large dispersion suggests is that we must be prepared to model a range of possible futures, explore how potential interventions will influence mobility identifying those that perform best under different conditions or are easier to adapt to them. It also suggests that these scenarios are going to be heavily context, not just country, dependent. Therefore, they will have to be carefully designed in each case, requiring new skills and close collaboration with other stakeholders.

For example, the AV part of one scenario may be that they become available in 2020, by 2027 they reach 10% of the fleet and by 2033 they are 20% of the fleet; this should be combined with other features like the proportion that is hired or owned and some key behavioural traits, for example attitudes to distant presence, openness to migration and globalisation.

An alternative scenario may involve availability by 2026, 2033 to become 10% of the fleet and 2040 to become 20% of fleet. Again, other aspects of the scenario may need to be defined as above.

The authors would like to thank all participants who freely contributed their time, thoughts and experience to this effort.