CHAUFFEURS FOR ALL

Timelines And Costs Of Driverless On-Demand Mobility From First Principles

AD PUNCTUM

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To The Point: A Summary Of This Report

Why might it interest investors? This report shows the link between actual travel patterns and the business model of mobility companies. It provides analysis that can be compared to the projections of companies you invest in.

Why might it interest automotive companies? This report analyses the key factors behind the adoption of on-demand mobility. It shows where there are areas of competitive advantage (both temporary and permanent) and demonstrates different scenarios for adoption rates, which may enable more sophisticated long-term sales and production planning.

On-demand mobility is a new and exciting area, promising a world where travel is better, cheaper, faster and safer. Although there are thousands of employees and many billions of dollars being put to work by start-ups and traditional car companies alike, business forecasts appear in the main to be subjective and based on individual intuition. This would make sense in unchartered territory but mass-transportation exists as a business today. It has existed for many decades.

On-demand mobility may change business models and the way travel is experienced, but it is not starting from scratch. People travel trillions of miles each year. There is plentiful data about how they do so. Our key findings are as follows:

Current data allows us to understand current average travel spending -- about $0.70 per mile. Many countries publish data on miles travelled, and modes of transport used. Mobility services are competing for a share of this spending.

Any big switch to on-demand travel isn't coming from rail, bus and air -- it comes from car ownership. The vast majority of passenger miles travelled are already by private car. Whilst there is potential for transfer from other modes (e.g. buses) and creating incremental travel, most on-demand market share is won by persuading people to give up their cars.

The potential revenue of a wholesale switch to on-demand is huge -- $6 trillion per year. Each year, the combined populations of the EU, USA and China travel more than 8 trillion miles by road, and this will increase with economic growth. Even without changing travel patterns, on-demand can compete with car ownership for a share of these trips.

Establishing a viable on-demand model faces a big problem -- capacity utilisation. This report shows that the pattern of "rush hours" holds across different regions and countries. Without sufficient capacity, people won't give up their cars. If they don't do that, on-demand struggles for market share. Utilisation assumptions above 50% are optimistic.

Driverless on-demand services will dramatically reduce car production -- by between 60% - 75%. Most planning assumptions are that production remains healthy because driverless fleets travel as many or more miles and use cars that quickly wear out. Unfortunately, the evidence shows purpose-built taxis last far longer than the most passenger cars. The average New York taxi lasts seven years and covers nearly half a million miles. London cabs last even longer.

Autonomous vehicles will be capable of most journeys sooner than people think -- the early 2020s. The classic driverless test of a narrow urban road filled with perils is a rarity. Around 70% of travel in rich countries is on major arterial roads and highways -- the technology is nearly capable of this now and will be ready around 2020. Driverless cars don't need to be capable on 100% of routes to capture share. The network will grow road-by-road, just like cable TV.

Widespread autonomy will take a significant share of travel by 2030 -- at least 40% in some markets. The rate of switchover depends on three things: price, technology and regulation. How travel habits change in response to price difference has been studied for many decades: cost parity with car ownership is the trigger for mass switching. Regulation and technology progress influence the growth rate -- share in 2030 could be 40% or 80% depending on how favourable they are. Regulators will drive operational and technology choices -- and they will probably demand electrification.

On-demand could increase miles travelled by around 25% compared to cars today. This would mean replacing public transport and increasing the travel of users with restricted mobility. Until on-demand can offer fares of about $0.40 per mile, most public transport users won't switch -- unless an alternative way of using existing subsidies can be found.

What does this mean? The adoption of on-demand mobility is going to depend primarily on cost. Although adoption scenarios vary in timing by a decade due to variation in regulatory and consumer preference, we ultimately see a route to $0.40 per mile across regions. Mass adoption will considerably reduce vehicle sales, so for carmakers the exact timing is academic. A bleak future beckons unless they can slim down, create a new product range and change their business model.

Introduction & Background

Although on-demand mobility growth, whether by ride-hailing companies such as Uber and Didi or from car-sharing firms such as ZipCar, has been rapid it still forms only a very small share of trips taken. It also remains unproven as a generator of profitable return. For this reason, this report looks at the demand-side factors that dictate success.

This analysis makes only one blanket assumption: human travel patterns are relatively constant and people have shown greater adaptability in changing methods of travel over the years than they have in changing their underlying pattern of behaviour. This does not mean that the nature of travel does not change -- the advent of rail shows that it does -- it is simply to say that it changes slowly. In the short to medium term, a new method of transport supplants existing modes whilst providing largely the same journeys, as cars did to horses at the turn of the 20th century.

The underpinning reason for this report was that although forecasts for on-demand growth are emerging at a total industry and specific company level, we found that many of the conclusions were not supported by any clear reference to fact. This is not to say that none existed -- it is to say that none was presented. Given the huge extent of data on travel being published by governments and supra-national bodies in addition to extensive research on human travel behaviour, it seemed appropriate to work towards conclusions for the future by looking at the way that people travel today.

This analysis draws on information published by a wide variety of sources: The EU; national governments such as the USA, UK and Germany; and municipal authorities including Transport for London and the New York City Taxi and Limousine Commission. We also gathered data from independent 3rd party reports and academia.

There was substantial information published around the following topics:

- Overall passenger miles travelled
- Overall freight miles travelled
- The modes of transport for moving both people and freight
- Rate of growth in travel distance over time and expected growth in future
- How people move throughout the day
- How much people are motivated by considerations such as price, convenience and privacy
- Public transport funding

As much as possible, this report uses data from a variety of locations when drawing any conclusions. Sometimes that shows a general conclusion to apply regardless of location. Sometimes it shows that different locations provide a range of answers. The aim of this report is to be objective and report what the data shows. There is no underlying agenda and the data has not been manipulated to support a single and definitive conclusion.

The data used in this report is focussed on the USA and European Union. Whilst we believe that this is sound in terms of understanding travel patterns and potential evolution in richer countries, we recognise the limitations in applying it to poorer countries. Our conclusions are based around the outlook for richer economics (including China) and do not preclude on-demand mobility taking a different path in poorer countries.

The report is structured as follows:

1. A look at the way that people travel today in different regions of the (rich) world and how much it costs them
2. Analysis of how efficient travel systems are today and what the implications are on costs for an on-demand business that aspire to gain scale and take share from private car ownership
3. An appraisal of the various factors which will influence adoption of an on-demand service, cumulating in different scenarios for growth
4. Applying information about public transport users and those with mobility restrictions to evaluate the potential additional market size of the business beyond private car users
5. How costs might further evolve to reach a target level of $0.40 per mile and attract public transport users
6. Some examples of what the on-demand customer experience could be like as the service evolves

1. How People And Things Move

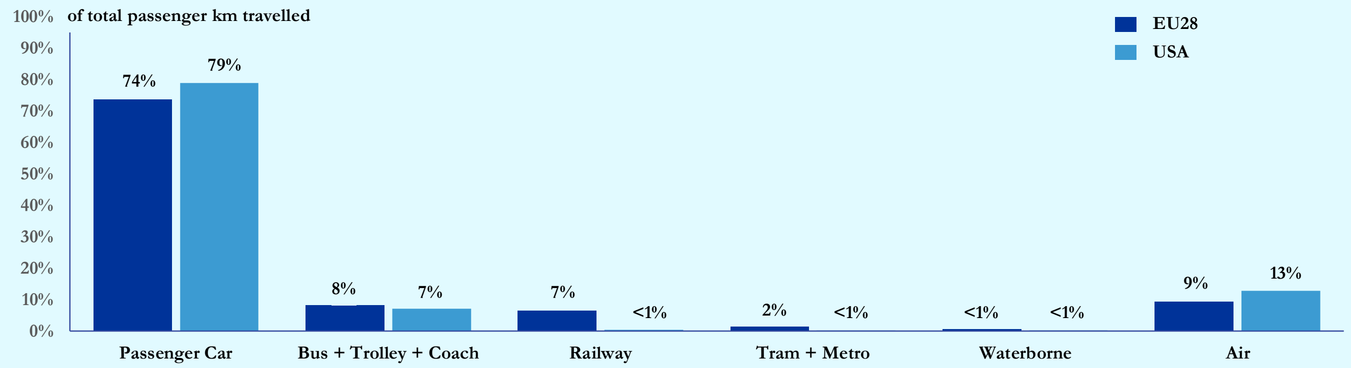
There are six primary methods of transport that people use:

- Passenger Cars (including taxi cabs)
- Buses (including coaches)
- Railways, trams and light rail or underground systems (e.g. New York subway, London Underground)
- Boat
- Aeroplanes

Freight uses road, rail and boat as a transport method with pipelines as an additional method for delivery of specific bulk goods (e.g. oil and natural gas). **Figure 1** shows the share of passenger transport in the US and European Union (28 states) for each method of transport in 2014. This demonstrates that in both regions, road is the dominant passenger transport method, accounting for over 80% of travel when cars and buses are added together. The share of rail is under 10% in the EU and almost nil in the USA. For both regions, boat transport has a minimal share and air travel has the second highest share of distance travelled after road.

FIGURE 1 | I Like To Move It, Move It

SHARE OF TOTAL PASSENGER DISTANCE TRAVELLED
FOR EACH MODE OF TRANSPORT IN 2014

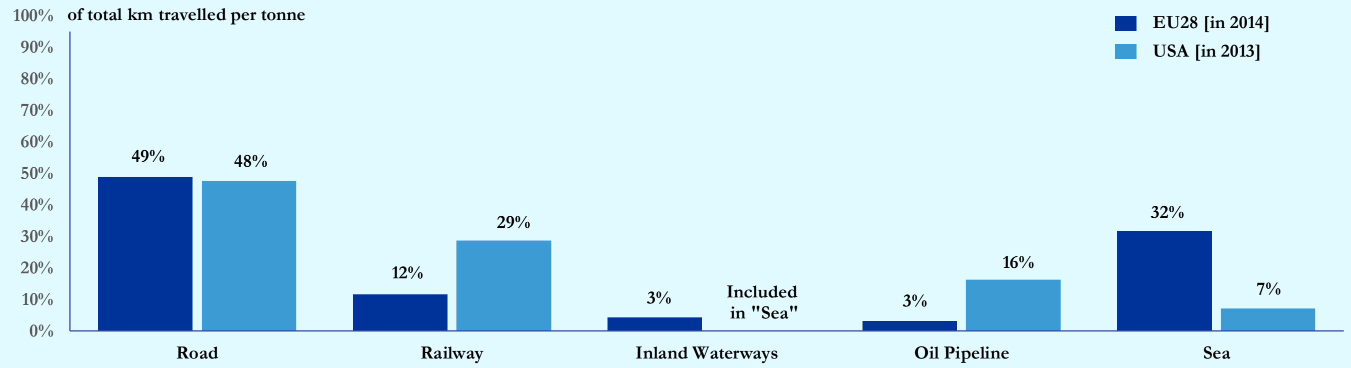


Source: Ad Punctum Research, European Commission

Figure 2 shows the share of freight transport in the US and European Union (28 states) for each method of transport. The years vary -- 2014 for the EU28 and 2013 for the USA. In both regions, road is the largest transport but has a lower share than for passenger travel. The share of rail is almost 30% in the USA. For both regions, bulk methods such as ship, rail and pipeline have significant shares.

FIGURE 2 | Loaded Up And Truckin'

SHARE OF TOTAL FREIGHT DISTANCE TRAVELLED
FOR EACH MODE OF TRANSPORT



Source: Ad Punctum Research, European Commission

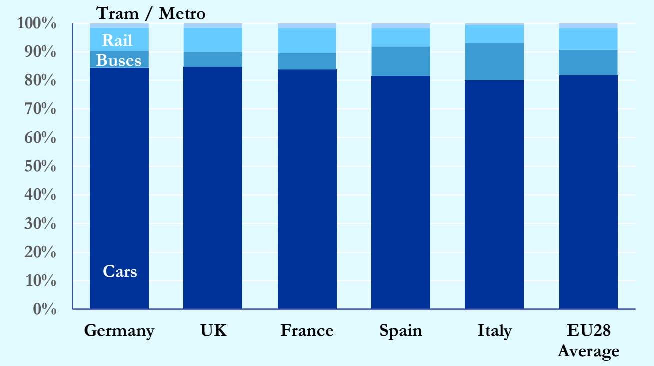
In addition to the regional view, the European Commission publishes country-by-country data on travel. This is useful in determining whether significant disparities exist, particularly since the European Union has members with a wide variety of wealth and infrastructure quality.

Figure 3 shows how the pattern of travel varies by EU country. This data is a subset of Figure 1 for land-based travel only. The trend is consistent: whether by country or EU average, passenger car share of travel is greater than 80%.

Figure 4 shows how the pattern of freight transport varies by EU country. This data is a subset of Figure 2 for land-based travel only. There is greater degree of variation by country in freight transport than with passenger travel, but only in the degree to which road transport dominates.

FIGURE 3 | Move Closer

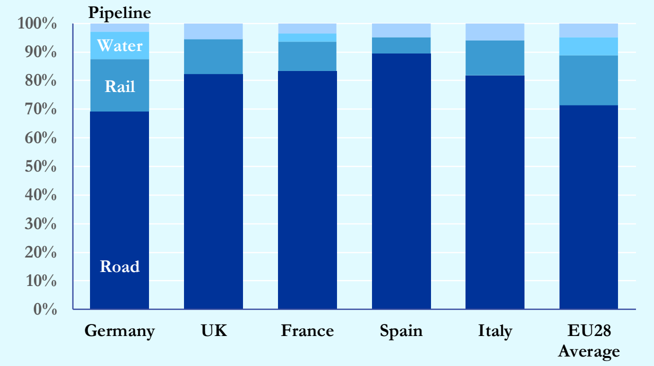
MODAL SPLIT OF PASSENGER TRAVEL ON LAND
EU28 COUNTRIES IN 2014 (EXCLUDES 2 WHEELERS)*



Source: Ad Punctum Research, European Commission

FIGURE 4 | I Did It My Way

MODAL SPLIT OF FREIGHT TRANSPORT ON LAND
EU28 COUNTRIES IN 2014

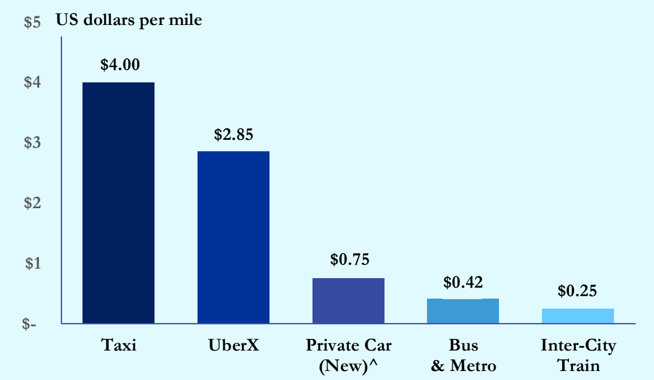


Source: Ad Punctum Research, European Commission

Figure 5 the travel cost of each of these modes of transport. This has been calculated using transport costs in different countries and cities, including both the US and European Union and represents the fare that the passenger pays. For bus and train this therefore includes any public subsidies, which are discussed later in this report. Arriving at a single rule of thumb average is a challenge, as **Figure 6** shows. In this example, metered taxi fares vary by city and also show significant variation between peak and off-peak levels.

FIGURE 5 | Money, Money, Money

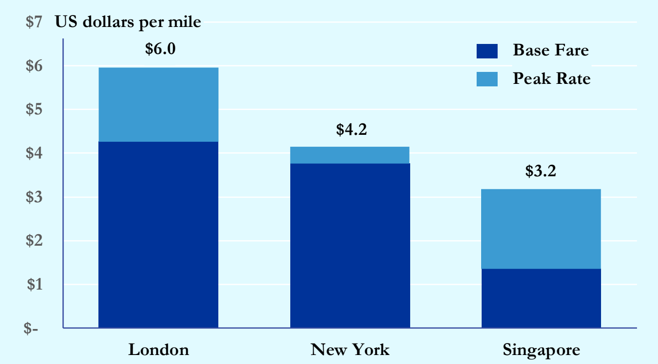
PASSENGER FARE/COST PER MILE* TO TRAVEL
DIFFERENT MODES OF TRANSPORT



Source: Ad Punctum Research ^ excludes parking costs and tolls

FIGURE 6 | Regional Disparity

TAXI FARES IN DIFFERENT CITIES
BASE AND PEAK FARE PER MILE*



Source: Ad Punctum Research, NYC TLC, TfL, ComfortDelGro

The calculation of vehicle cost includes the elements of wear and tear, fuel, depreciation and purchase costs but it does not include parking costs and tolls -- figures that can vary by a large degree across regions. We have also not included in this assessment the average cost for used vehicle usage, where the cost would be lower than a new car for depreciation, but higher for fuel (fleet average fuel economy has been improving over time) and servicing costs.

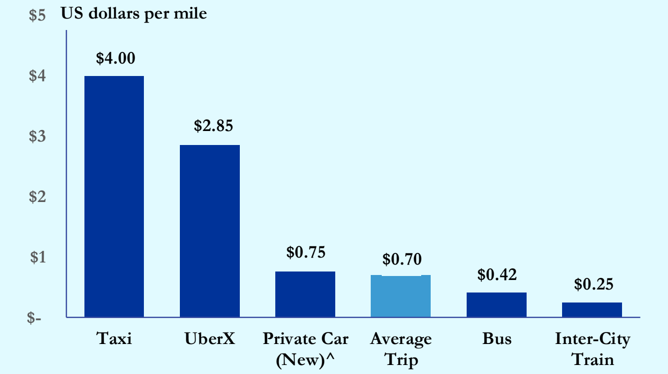
NOTE: [Fig. 3] powered 2 wheeled vehicles (e.g. mopeds, motorcycles) made up an incremental 2.14% of passenger miles travelled in 2014
[Fig. 5] the analysis is based on appropriate average usage for each mode (e.g. taxi trip = 2.6 miles, car = 10,000 miles per annum)
[Fig. 6] based on a 2.6 mile trip (using NYC TLC data), assumes trip is based on travel distance rather than stationery time or a mix of the two

By combining the shares of transport modes and their per mile cost, a weighted average cost per mile travelled for land-based methods can be calculated. Although slightly different based on the mix of transport in the US and EU28, the figures are within 5% of one another.

Figure 7 shows the result. The **average cost per mile travelled is $0.70** in current US dollars. The figure for the EU is slightly lower, $0.68 per mile and the US figure is a little higher, $0.72 per mile. **Figure 8** shows the amount of passenger miles travelled in 2014 on the roads of the EU28, USA and China -- together these three territories account for a significant share of total global travel and have the right infrastructure conditions (e.g. road quality and density) for on-demand mobility to be a success once it can operate at scale and cost.

FIGURE 7 | I Can See Clearly Now

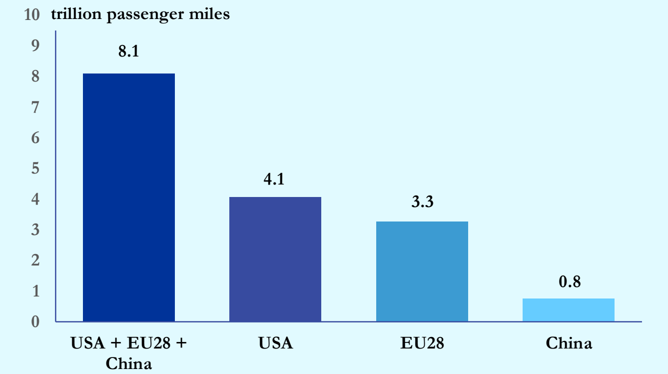
PASSENGER FARE/COST PER MILE TO TRAVEL DIFFERENT MODES OF TRANSPORT



Source: Ad Punctum Research ^ excludes parking costs and tolls

FIGURE 8 | Just Imagine The Possibilities

PASSENGER TRANSPORT BY ROAD 2014 DATA



Source: Ad Punctum Research, European Commission

Combining these values -- 8.1 trillion miles at $0.70 per mile -- gives a **revenue pool of $5.7 trillion** at 2014 conditions. Miles travelled is in fact increasing each year, as economic growth continues. The degree to which travel may have increased by 2040 is discussed later in this report.

In summary, from looking at the way that people travel today in different regions of the world, it is possible to conclude the following:

- **Current average spending on land-based travel is about $0.70 per mile** -- the figure is slightly higher in the US and a little lower in the EU28. This is the share of spending that on-demand mobility companies are competing for. Although some modes of transport (e.g. public buses and rail) are substantially cheaper than cars, this does not meaningfully skew the average because of the dominance of the passenger car for land travel
- **Any big switch to on-demand travel isn't coming from rail, bus and air -- it comes from car ownership.** The clear majority of passenger miles travelled are already by privately-owned car. Whilst there is potential for transfer from other sources (e.g. buses) and creating incremental travel, our analysis is that this amounts to between 15% - 25% of the market. Most on-demand revenue comes from people subscribing to a service that covers all their travel needs rather than buying a car. The 15% - 25% figure is justified later in this report.
- **The potential revenue of a wholesale switch to on-demand is huge -- $6 trillion per year.** Already the population of the EU, USA and China collectively travel more than 8 trillion miles annually, a figure that will increase through economic growth. Changing from private car ownership to on-demand unlocks that revenue without even changing travel behaviour.

2. The Realities Of Mass Transit

Having demonstrated that there is a healthy market for on-demand transport to serve -- a significant demand in major territories -- and a clear price target. The question is whether or not that price can be achieved profitably? Under current conditions, the answer is no.

The single biggest issue with price is the driver. Private car usage provides the driver for free (unless the driver is able to demonstrate a more valuable use of their time and presumably if they could be doing this they already use a mode of transport that enables them to work -- Billionaires do this).

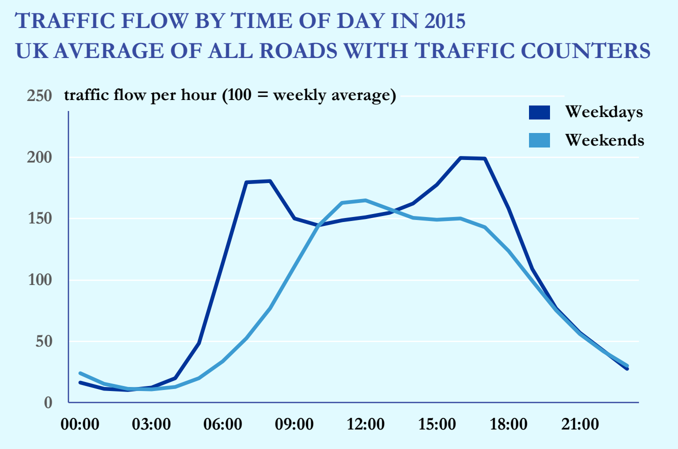
The second greatest challenge is having a fleet utilisation that enables efficient cost recovery for the operator. This has unfortunately been overlooked in much of the financial analysis published thus far (it may have been covered comprehensively in unpublished research). Much of the current thinking works as follows: a private passenger car is utilised about 5% of the time, that creates 95% under-utilisation and so by designing a more efficient system, an improvement of almost 20 times is possible, creating untold riches. This line of thinking has an unfortunate flaw.

As **Figure 9** demonstrates (for the UK), although it may be true that the average vehicle is only around 5% utilised, their utilisation often takes place at around the same time. This means that the operational efficiency can only be smoothed to reach a near-100% efficiency through one or both of the following:

- **Shift the traffic to an entirely different time of day and smooth out the peaks and troughs** -- a clear candidate here is to move freight to less popular times and somehow utilise the same vehicle that transports passengers at different times. Otherwise this means persuading people to go to work at one o'clock in the morning.
- **Increase the passenger density at busy times --** this leads to a smoothed distribution of demand however this approach cannot solve the utilisation problem. The off-peak demand is so low that peak to off-peak travel densities would be of the order of 20:1, too high for both passenger comfort and efficient dynamic routing. Since this data reflects vehicle traffic per hour, rather than passenger numbers (more of which later), it inherently reflects higher traveller densities at peak times because vehicle types that can accommodate more people (e.g. buses) count the same regardless of their occupancy.

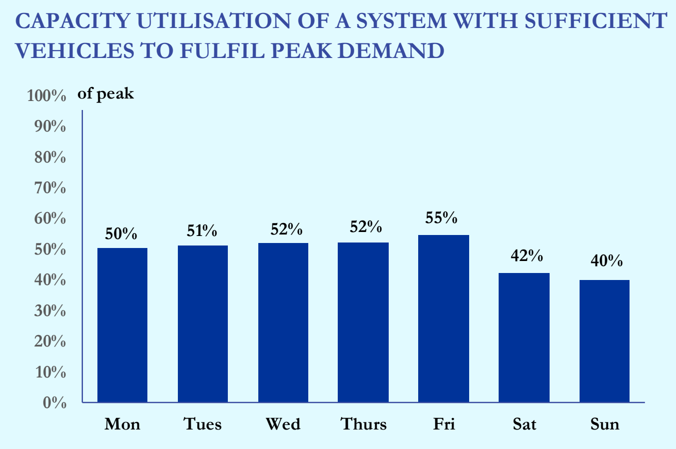
Figure 10 shows how the capacity utilisation of a UK fleet would vary by day since traffic flow is not constant across the week. This creates an overall capacity level of 49%.

FIGURE 9 | The Time Of Our Lives



Source: Ad Punctum Research, UK Department for Transport

FIGURE 10 | So Much Capacity



Source: Ad Punctum Research, UK Department for Transport

These graphs are based on average data across a year so an assumption of the absolute peak could reasonably be assumed as higher than the annual average level. As Figure 9 shows, the problem is simply that between the hours of 9PM and 5AM the demand is naturally far lower than during the day. This pattern recurs across territories for the simple reason that human beings tend to travel less when they are asleep. Ad Punctum's anecdotal analysis is that this stems from: lower driving performance whilst asleep, the relative discomfort of a moving vehicle as opposed to a bed (unless you are a new-born baby) and the disruption caused to sleeping by people who drive with their headlights on constant full beam.

In addition to the UK, the phenomenon of road traffic peaks and troughs associated with rush hour has been recognised in both the USA and Germany, with each putting their own national spin on the concept. In the US, a light-hearted comedy motion picture franchise bearing the "Rush Hour" name was created. In Germany, the Federal Highway Research Institute) has turned the study of rush hour into an art form and recognises seven different types of traffic flow throughout the day:

1. Strong pronounced morning peak
2. Morning peak, secondary lower peak in the afternoon
3. Relatively balanced distribution of traffic throughout the day
4. Double peak (morning and afternoon both about the same size)
5. Afternoon peak following a small peak in the morning
6. Strongly pronounced afternoon peak
7. Above average share in the morning with steadily falling demand after that

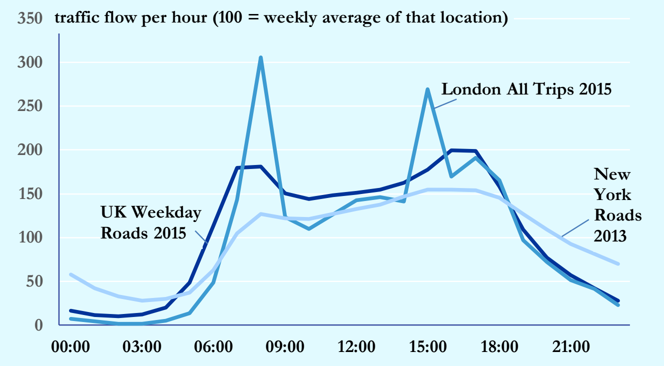
Although the bullet points above are our own translation, they aren't a joke. That is honestly how the values are published in Germany. Although not illustrated here, the pattern of German and US travel by hour is similar to the UK.

Figure 11 gives a clearer idea of how the nature of travel flow varies. Alongside the UK weekday line from Figure 9, the chart shows the traffic flow on New York roads (also averaged over a full year but 2013 rather than 2015) and London trips by all modes of transport. The profile of the London data gives some indication that road traffic flow already represents the effect of higher passenger density since although in most hours London is similar to average UK weekday roads, the peaks are more pronounced. In New York, although the same pattern of higher daytime versus night time travel exists, the traffic flow is better distributed throughout the day than in the UK examples.

Figure 12 brings together the idealised capacities based on the data in different locations. From this we are able to observe a range across locations, between low-40% to mid-60%. The three country-level figures are very similar at just over 50%.

FIGURE 11 | I'm In Love With The Shape Of You

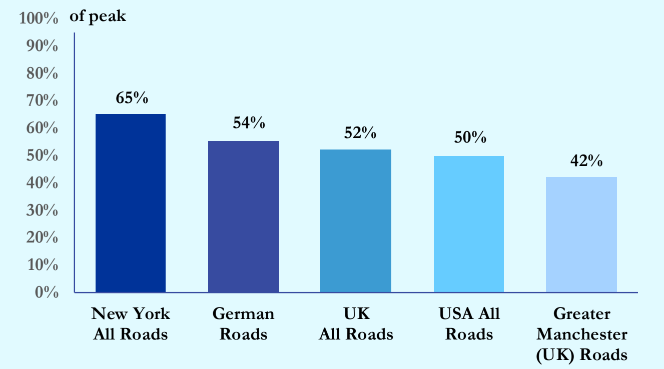
TRIPS BY TIME OF DAY (WEEKDAYS)
DIFFERENT GEOGRAPHIC AREAS



Source: Ad Punctum Research, Department for Transport, TfL, City of New York

FIGURE 12 | Not So Very Different

INDICATED WEEKDAY OVERALL CAPACITY UTILISATION
AT CURRENT PASSENGER DENSITY



Source: Ad Punctum Research, UK DfT, TfL, City of New York, BAST, US DfT, TfGM

Given that potential utilisation clusters 50% on average at a national level, we suggest this as a benchmark (it may be slightly optimistic given absolute peaks in demand on especially busy days). Based on the findings above, our suggestion is that the following are key tests of on-demand mobility claims:

- **Is the intent to service peak demand?** If the answer to this is "no" then there will be insufficient capacity to persuade people to give up their vehicles and market share will be severely curtailed. As this report will demonstrate, the opportunity to provide mass-transit looks too good to refuse so someone will be aiming to do this.
- **Is the capacity utilisation more than 50%?** If the answer to this is "yes" then either: (1) it appears over-ambitious given the actual travel data; (2) the company in question is targeting only a limited application in a territory which it knows has a smoother natural flow of traffic; or (3) there is a very good plan to smooth traffic across the day.

How to deal with the capacity problem? The initial reaction of most people encountering the problem is straightforward: increase the passenger density (also known as occupancy rate). With more people travelling together, fewer vehicles are required. This logic has two significant drawbacks (which isn't to say that the approach is wrong, but it may be of only limited use):

- The average traffic flows already include vehicle types that have higher occupancy levels at peak times (e.g. buses) therefore converting all road traffic to on-demand inherently includes an "occupancy rate challenge" to meet the same levels as today. Given that bus usage today accounts for less than 10% of all miles travelled, expecting a clever way to boost occupancy may not be unreasonable but expecting better performance than today could be.
- Occupancy levels can be increased dramatically (as anyone taking an underground train in London during rush hour will know) but this comes at a cost -- the fare that they are prepared to pay is lower. In the cases of buses and local trains, the fare per mile is only slightly more than half of the price people are prepared to pay to use their own car. There has been substantial research into occupancy levels over several decades and the ongoing theme is that passengers value privacy and will only exchange it for two other commodities: faster transit time or lower prices.

Perhaps more promising, but also requiring greater advances in technology, would be re-purposing the vehicle so that it could operate as a freight vehicle at off-peak times for people movement. In its simplest form, this idea might look like the GM AUTOnomy concept of 2002 where the entire driven vehicle was contained within a "skateboard" rolling chassis (not so different in concept from body on frame vehicles of yesteryear, just better packaged). Figure 13 shows this rolling chassis that could be joined to any number of different bodies as in Figure 14. GM's intent for this concept was to aid manufacturing simplicity -- do the more complex skateboard manufacturing in one central plant globally and locally manufacture the bodies. Since this is still the realms of science fiction, we can extend the concept to a vehicle where the body is replaceable, with a short changeover time, so that function can be swapped from freight to passenger transport.

FIGURE 13 | Flat As A Pancake

GM AUTONOMY CONCEPT -- CHASSIS ONLY

Source: General Motors

FIGURE 14 | Rock Your Body

GM AUTONOMY CONCEPT -- CHASSIS & EXAMPLE BODY

Source: General Motors

Why bother going to the trouble of changing the body? The answer lies in pack density. In commercial mode the vehicle body would in essence be a large rectangle whereas in passenger mode it might be sleeker and more lounge-like. Then again, this somehow still seems traditional and maybe we aren't thinking out of the box enough (there are some other practical advantages to a commercial-only set up such as weight saving from passenger niceties like seats). Perhaps people will want to travel in rectangles in the future?

How competitive can on-demand mobility become on price? We can see a route to a per mile cost of $0.60, which would undercut private car ownership but still be more expensive than public transport (from the point of view of the fare-paying user). However, this is totally dependent on the advent of driverless technology. At present, the cost of wages account for around half the operating cost of a taxi company. This is the total staffing cost including support staff, so even removing the driver will not eliminate 100% of staff costs.

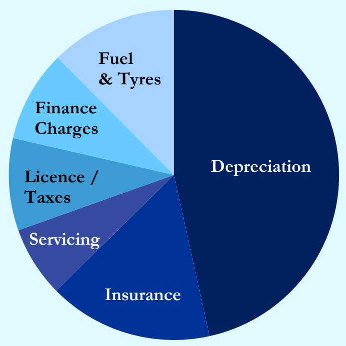
At present levels, even with the application of technology to improve fleet efficiency, the cost of Uber X (the service where the customer is guaranteed they do not have to share the vehicle, apart from with the driver) given in Figure 5 was

$2.85 -- and at this level Uber still might be making a loss (since they don't break out operating costs versus "investment" in market share it isn't possible to be certain). To see how driverless cars can become competitive on price with private cars, the best starting point is the cost of private cars today.

Figure 15 shows the different elements that constitute the benchmark of $0.75 per mile. Depreciation makes up almost half of the cost. **Figure 16** demonstrates the psychology of depreciation. Although in functional terms, a car with a lifespan of 10 years or 150,000 miles could be treated as having a straight-line depreciation, the retail market is very different. Customers value "newness", this leads new car buyers to carry a cost burden versus the idealised price. In today's world, this is a theoretical exercise but in a world of driverless mobility it is an important part of the business case.

FIGURE 15 | Where Does It All Go?

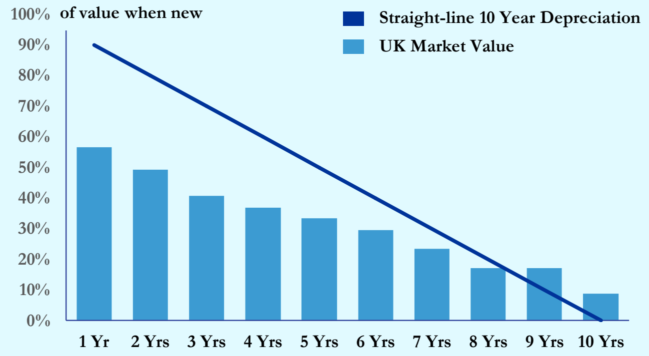
BREAKDOWN OF US PRIVATE CAR OWNERSHIP COSTS BASED ON A VEHICLE COVERING 10,000 MILES PER YEAR



Source: Ad Punctum Research, AAA Your Driving Costs 2016

FIGURE 16 | Compare The Market

RESIDUAL VALUE OF VEHICLE WITH 10YR / 150K LIFE PUBLIC OPINION VERSUS USEFUL LIFE

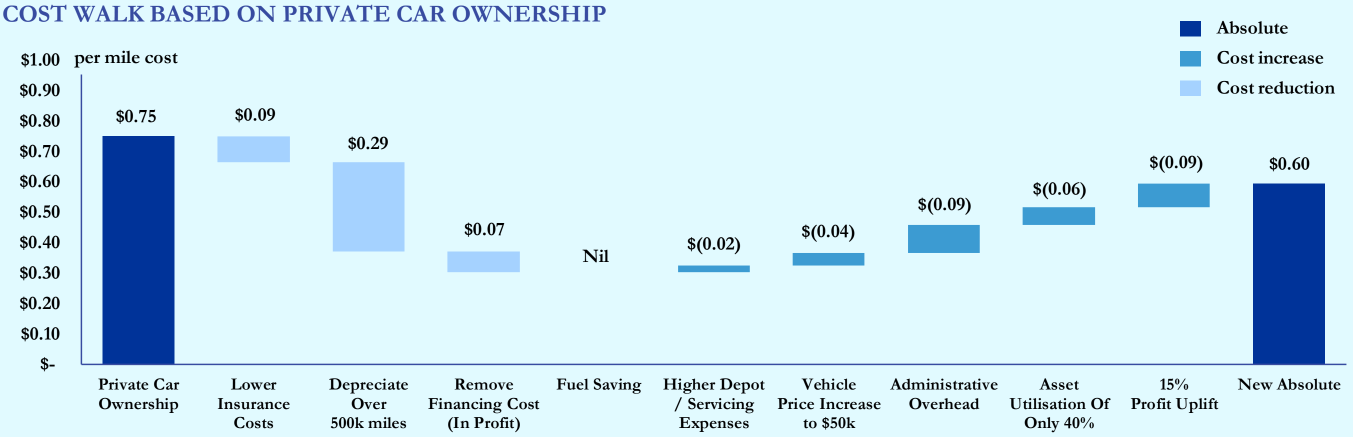


Source: Ad Punctum Research

Figure 17 shows how the cost equation for driverless vehicles could look. There are three key elements to the cost walk from private ownership: (1) Lower operating costs relating to the efficiency of driverless vehicles operated as a pool instead of private vehicles; (2) higher per mile cost relating to vehicle robustness and increased cleaning and light servicing and finally (3) overheads and profit that the corporation requires to deliver the service and reward its owners.

FIGURE 17 | I'll See You When You Get There

COST PER MILE FOR A DRIVERLESS VEHICLE IN OPERATION (OCCUPANCY OF ONE)
COST WALK BASED ON PRIVATE CAR OWNERSHIP



Source: Ad Punctum Research

Lower insurance Costs result from the greater safety of driverless vehicles. Current forecasts are for driverless vehicles to ultimately reduce accidents by 90%. Not only will the number of accidents be reduced, but the number of the most serious accidents will decrease by even more. This is simply because driverless vehicles have considerably higher spatial awareness than human beings and they will take fewer risks. Our analysis assumes a 70% reduction in cost versus today, reflecting the lower accident level but higher premiums to cover the liability of carrying a 3rd party.

Lower depreciation comes through the way that the vehicle is used. This analysis takes New York taxis as the benchmark. New York taxis are retired after seven years (if they are sufficiently well maintained in order to pass inspections during that time). After covering an average of 70,000 miles each year, New York taxis reach half a million miles before being retired. This is a substantially different assumption to those being made by some other analysts who assume that the vehicles will simply be replaced after 150,000 miles but it is one which we think stands up to scrutiny. Alongside the New York example, we looked at the life of purpose-built taxis from London Taxis International. **Figure 18** shows that most vehicles are over 5 years old so the 7-year life adopted by New York seems reasonable. Partially offsetting the longer life, we assume the vehicle becomes more expensive. This cost will be for driverless technology, electrification and overall vehicle robustness. Our assumption is a $20,000 increase in purchase cost ($50,000 per unit in total). One could assume that these costs would drop over time -- thus lending conservatism to our forecast. This analysis also shows that the business case can be made to work with vehicle unit costs much more expensive than today's retail vehicles.

We release the consumer financing costs as these will be covered by the operator's profit. There is a saving here since consumer financing costs reflect higher rates of depreciation (i.e. retail consumers borrow more because the car depreciates more quickly than the straight line to end of life method).

We assume that the commercial vehicle incurs depot costs of $7.50 per day. This pays for out-of-town storage during off-peak times and an assumption of being cleaned twice per day. Within these costs we assume that servicing cost per mile falls by 25% because economies of scale improve -- for instance, developing a more efficient servicing process and negotiating bulk discounts on consumables such as tyres. When cars can drive themselves, local garages lose an advantage and their small size becomes a hindrance. Vehicles can go to out-of-town regional facilities, more like factories.

The depreciation advantage is partially offset by capacity under-utilisation. This could be represented as overly-fussy analysis but we wanted to draw out that the fleet capacity utilisation is a key operating metric here. Our assumption is that the fleet must have sufficient vehicles to meet demand peaks, which increases holding costs. Separating the underlying depreciation from the asset efficiency enables different capacity utilisation assumptions to be made.

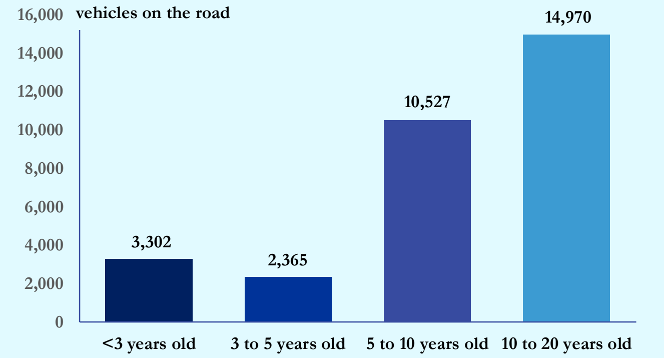
The company brings an overhead of 25% for staffing and systems and requires a profit, assessed as 15% of costs. This is benchmarked against airlines, which typically achieve a 10% - 15% return on cost of sales.

The scenario above is based on a system which is providing mass availability at scale (e.g. a substantial regional scheme). Ramp up costs would diminish this cost position and finding ways to improve capacity utilisation will benefit it.

All these cost savings take their toll on car sales. As **Figure 19** shows, rich country car ownership is high -- between 0.45 and 0.75 cars per head of population (which includes non-car owners such as children and the very elderly).

FIGURE 18 | Oldie, But A Goodie

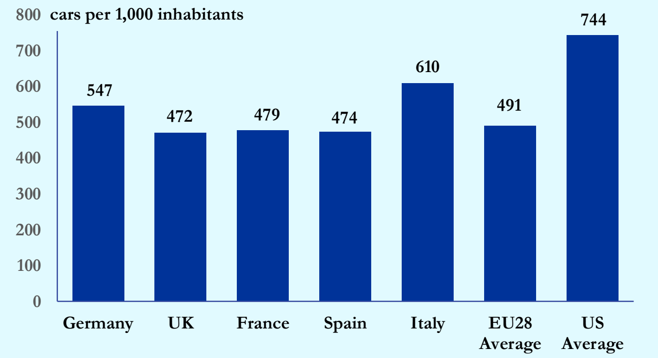
AGE OF SPECIALISED UK TAXIS
STILL ON THE ROAD AS OF 31ST DECEMBER 2015



Source: Ad Punctum Research, UK Department for Transport

FIGURE 19 | What Have We Got To Lose?

VEHICLE OWNERSHIP LEVELS
EU28 COUNTRIES IN 2014, USA IN 2009



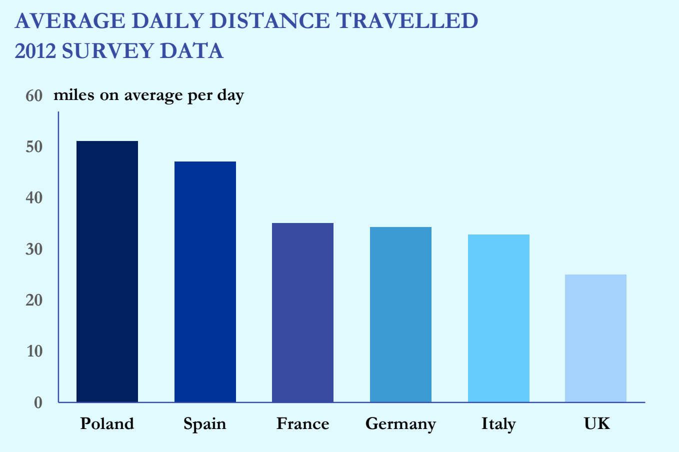
Source: Ad Punctum Research, European Commission, US NHTS

Two charts help to illustrate the extent to which private car ownership inflates the level of vehicles needed by comparing to a system which uses on-demand assets to fulfil the same travel requirements.

Figure 20 shows the amount of travel each vehicle covers in a day. The data is from a survey undertaken for the European Commission. As a point of note, the survey covered car usage (for both personal and business purposes) but did not look at commercial vehicles. Although average distances vary by country, in all cases they are some way short of 100 miles per day. The average New York taxi which covers 70,000 miles per year at an over-optimistic assumption of 100% uptime (which depresses the daily average) drives an average of 191 miles each day. This is nearly four times the daily travel of Polish drivers, the farthest motoring nationality in the survey, and more than eight times that of British drivers.

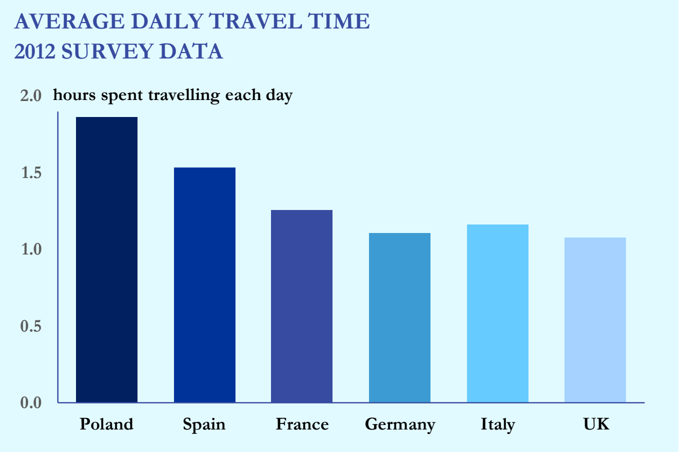
Looking at **Figure 21**, the inefficiency becomes clearer, the average travelling time is under 2 hours. Even allowing for the very small amount of travel between 21:00 and 05:00 each day, private cars are in use between one eighth (2 hours) and one sixteenth (1 hour) of the normal travelling day. The graph figures are for European Union countries but in the USA the same pattern can be seen -- average travel time in 2009 was around one hour.

FIGURE 20 | I Go Driving In My Car



Source: Ad Punctum Research, European Commission

FIGURE 21 | Don't Stop Moving



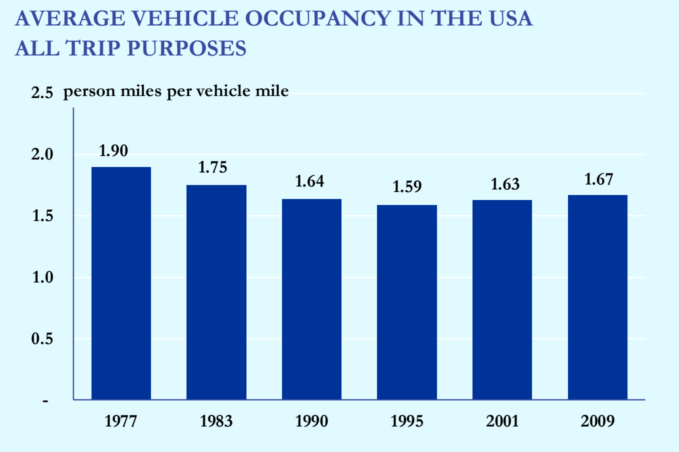
Source: Ad Punctum Research, European Commission

Combining information from Figures 20 and 21 provides an impression of average traffic speeds: somewhere between low 20s and low 30s miles per hour (mph) depending on the country and day of the week. Values cluster at around 30 mph.

The phenomenon of a travel time "budget" seems to extend across countries and population densities. US household data for towns and cities shows that regardless of the size, the average travel time is very similar -- just under an hour.

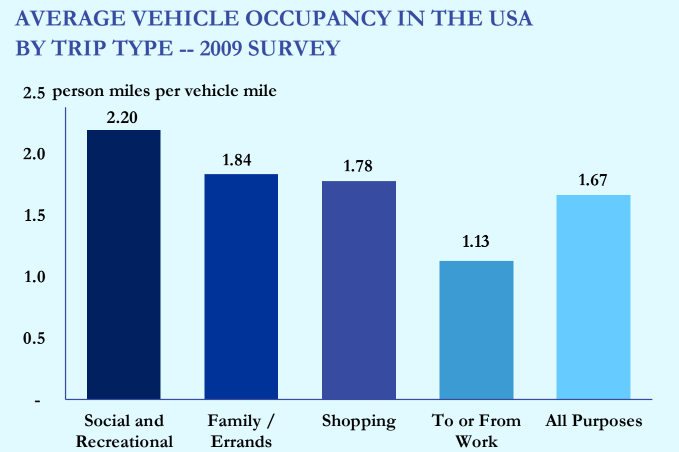
The final key element in determining capacity is occupancy level. **Figure 22** shows the occupancy level for passenger cars (including light trucks) in the USA. For the past 20 years it has sat between 1.6 and 1.7 occupants on average. **Figure 23** shows that this average is a function of the type of trip. Work trips have the lowest occupancy at just over 1.1 (a pattern that has remained steady since 1990), whereas for social trips it is 2.2.

FIGURE 22 | All Friends Together



Source: Ad Punctum Research, US NHTS

FIGURE 23 | Who's With Me?



Source: Ad Punctum Research, US NHTS

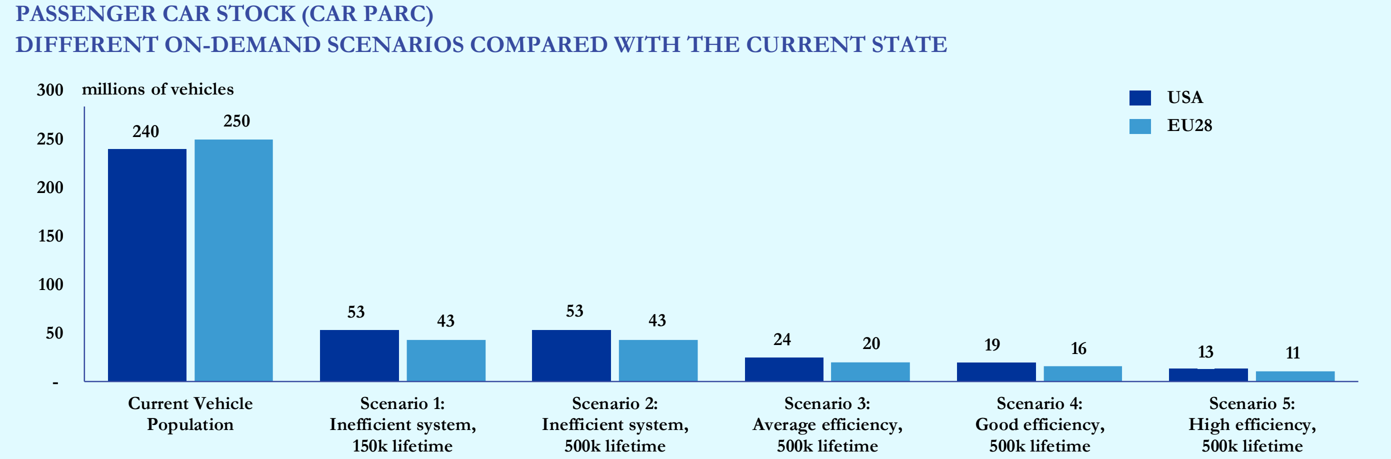
Although sadly the European Environment Agency seems to have become disinterested in tracking passenger occupancy since 2010, at that time it was showing levels of 1.54 for each car in Western European countries, with Eastern Europe averaging 1.8 people per car on average (Slovakia was the highest at 2 people per car). Eastern European countries were therefore close to the level Western European countries had seen in the early 1980s when average occupancy was between 1.70 and 1.80 people per vehicle. This could be taken as an indication that as populations grow richer they prefer to travel more separately (they also buy more cars). The trend of US occupancy in Figure 22 appears to indicate something similar (it also suggests that the trend stabilises).

We have now determined that the key factors influencing the vehicle requirement for an on-demand system are as follows:

- Capacity utilisation -- current road systems are between 40% and 65% with clustering at 50%.
- Average traffic speed -- current road systems are between 20mph and 35mph with clustering at 30mph.
- Average occupancy levels -- current road systems are between 1.1 and 2.0 with clustering at 1.6.
- Vehicle lifetime -- industry rule of thumb for retail vehicles is 150,000 miles but taxis typically last 500,000 miles.

Figure 24 shows how the total population of cars required would change for different scenarios of on-demand mobility. Each of scenario 1 to 5 assumes mass-usage of on-demand mobility, which is to say that once travel cost per mile reaches less than $0.70 (Figure 17 showed a path to a profitable $0.60 per mile) with complete reliability of service, the imperative for private vehicle ownership disappears for all but a trace element of the population (public transport fares, a different challenge, are discussed later in this report). **Figure 25** shows the effect of these scenarios on annual vehicle demand.

FIGURE 24 | Dude, Where's My Car?



Source: Ad Punctum Research, European Commission

The scenarios evaluated were as follows:

Scenario 1: Inefficient System -- Assumes an average speed of 20 miles per hour (slightly worse than the low end of currently observed levels), occupancy of 1.1 (comparable to current observed levels for commuting in vehicles), a 40% utilisation rate (about the same as utilisation levels in British cities) and a 150,000 mile vehicle lifetime. At these levels, each vehicle covers around 70,000 miles each year and has a lifetime slightly longer than two years.

Scenario 2: Inefficient System -- Assumes an average speed of 20 miles per hour (slightly worse than the low end of currently observed levels), occupancy of 1.1 (comparable to current observed levels for commuting in vehicles), a 40% utilisation rate (about the same as utilisation levels in British cities) and a 500,000 mile vehicle lifetime. At these levels, each vehicle covers around 70,000 miles each year (as for scenario 1) and has a lifetime slightly longer than seven years.

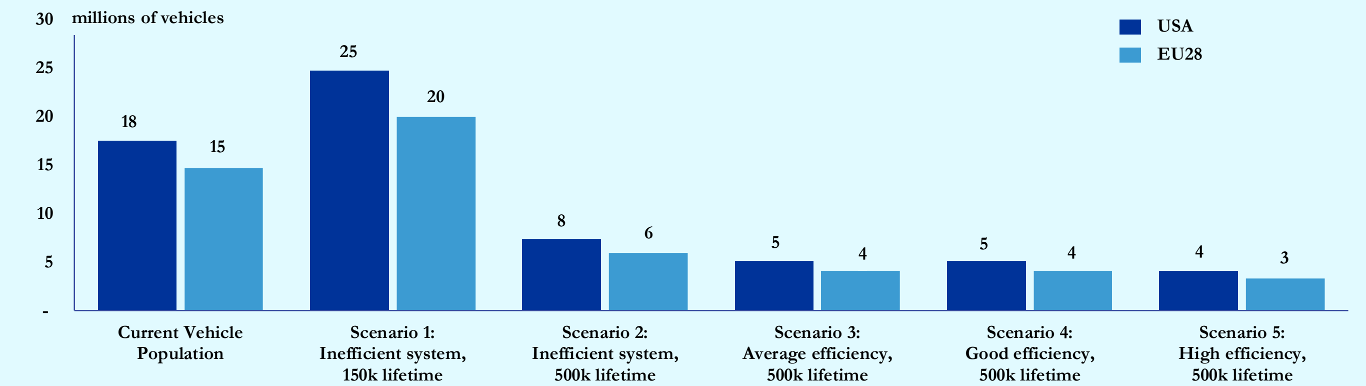
Scenario 3: System with Average Efficiency -- Assumes an average speed of 30 miles per hour (similar to where currently observed levels cluster), occupancy of 1.6 (comparable to current observed levels in USA and Western Europe), a 40% utilisation rate (about the same as utilisation levels in British cities) and a 500,000 mile vehicle lifetime. At these levels, each vehicle covers around 105,000 miles each year and has a lifetime of slightly less than five years.

Scenario 4: System with Good Efficiency -- Assumes an average speed of 30 miles per hour (similar to where currently observed levels cluster), occupancy of 1.6 (comparable to current observed levels in USA and Western Europe), a 50% utilisation rate (about the same as national averages in for UK, Germany and USA) and a 500,000 mile vehicle lifetime. At these levels, each vehicle covers around 130,000 miles each year and has a lifetime of slightly less than four years.

Scenario 5: System with High Efficiency -- Assumes an average speed of 35 miles per hour (upper end of currently observed levels), occupancy of 2.0 (upper end of observed levels, similar to Eastern Europe today), a 50% utilisation rate (about the same as national averages in for UK, Germany and USA) and a 500,000 mile vehicle lifetime. At these levels, each vehicle covers around 150,000 miles each year and has a lifetime of slightly over three years.

FIGURE 25 | The Future Doesn't Look Bright

ANNUAL NEW PASSENGER VEHICLE DEMAND (EXCLUDES COMMERCIAL VEHICLES)
DIFFERENT ON-DEMAND SCENARIOS COMPARED WITH THE CURRENT STATE



Source: Ad Punctum Research, ACEA, Business Insider

The first thing that becomes clear from these scenarios is that even using low-end real-world values for operating efficiency, alongside vehicle lifetimes demonstrated in practice by taxis (Scenario 2), the vehicle requirement is reduced drastically -- vehicle population is around a fifth of its current level and new vehicle demand drops by more than half.

By achieving average real-world operating efficiency with taxi lifetimes (Scenario 3), vehicle population drops to around 10% of the current level and new vehicle demand drops by more than two thirds.

By achieving the upper end of real-world operating efficiency with taxi lifetimes (Scenario 5), vehicle population drops to less than 10% of the current level and new vehicle demand drops by over 75%.

One silver lining for carmakers, if vehicles become more expensive then industry revenue will not fall as far as the unit shipments. There is also the one-time dividend that comes from upgrading the fleet to on-demand levels. In addition, Figures 24 and 25 reflect the current level of person miles travelled. A fair expectation is that miles travelled will continue to grow, regardless of transport method -- therefore the percent drops are representative of on-demand versus car ownership, but the absolute figures may not be. It also may be that some carmakers are far more popular among on-demand providers (e.g. Uber may decide its customers should all be driven in BMWs with not a Ford in sight).

All these scenarios rest on an assumption of widespread on-demand mobility. Understanding the technical, consumer and regulatory factors behind that is the subject of the next section of this report.

In summary, from looking at the operating performance of travel systems today, it is possible to conclude the following:

- **Establishing a viable on-demand model faces a big problem -- capacity utilisation.** The pattern of "rush hours" holds across different regions and countries. Utilisation assumptions above 50% are optimistic. Without sufficient capacity, people won't give up their cars. If they don't do that, on-demand struggles for market share.
- **Driverless on-demand services will dramatically reduce car production -- by between 60% - 75%.** The privately-owned car is so inefficient in terms of utilisation that even lower-end assumptions for system efficiency drastically reduce the number of new cars needed.

3. Times Are Changing

This report has already demonstrated that driverless vehicles are the key to achieving low per mile costs and reaching widespread adoption of on-demand transport. At an average speed of 30 miles per hour (consistent with real world norms) and a fully-fringed driver cost of $15 per hour (not a generous assumption for Western Europe and the USA), the driver adds $0.50 cents to each mile travelled. In heavy traffic, moving at 10 miles per hour, the cost becomes $1.50 per mile.

Establishing mature market conditions for driverless on-demand mobility is one thing but many people are interested in something more practical: the timeline. The advent of driverless cars will be governed by the following factors:

- The ability of the sensor set to understand road conditions
- The ability of artificial intelligence to analyse data collected by the sensor set and make decisions
- Regulatory acceptance -- how proactive governments are in getting driverless cars onto the roads
- Consumer acceptance

This section will demonstrate that it is the second and third of these factors are the most unpredictable.

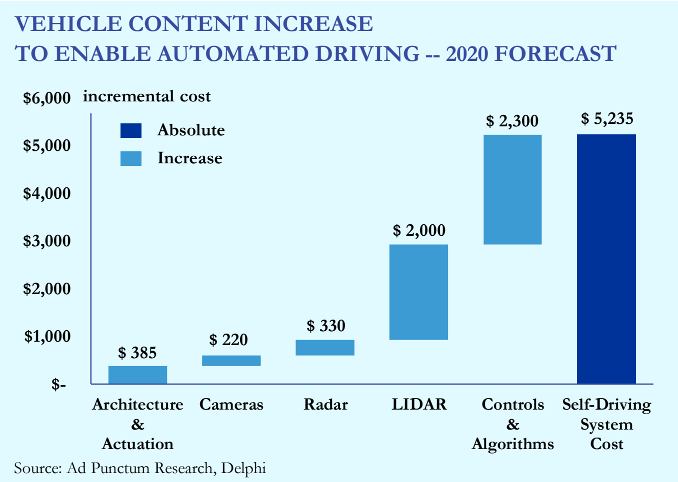
Sensor set development has been underway for several years and although there is no complete consensus, a pattern has emerged. Through a combination of machine vision (cameras), conventional radar, laser range-finding (LIDAR), mapping data and environmental assessment, a driverless vehicle can determine more about road conditions than human drivers (excepting those with near super human powers of concentration and risk detection). This is out of necessity: a safety critical system such as a self-driving car must have multiple layers of redundancy, which is to say that even if more than one part of the sensor set is lost (for instance the vision and the mapping), the car must be able to continue to operate, at a minimum to stop safely. The standards to which self-driving vehicles will be held are far higher than for humans -- it is unacceptable for a driverless car to become “distracted”. Although questions will remain over the actions a vehicle should take in certain situations, it is imperative that the car will have a wide range of data with which to decide what to do next.

Through development, sensor sets have proven themselves capable of detecting people, objects and changes in the physical environment. The sensors are not yet perfect. They still find it difficult to master the same road conditions that befuddle human drivers: heavy rain and icy conditions.

Led by Tesla, carmakers have started putting semi-autonomous technologies in the hands of private car owners. Looking towards 2020, several manufacturers are promising hands and eyes off driving on highways (although the time which you can let the car drive itself varies by brand). So far, these systems have been based on a combination of mapping, cameras and radar but have not included LIDAR.

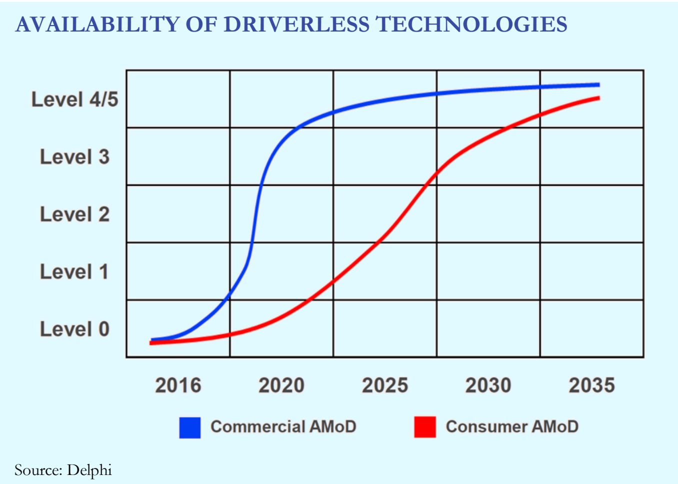
Figure 26 shows a driverless system cost assessment by Delphi (a leading supplier). **Figure 27** shows Delphi’s view that these technologies will be production ready between 2020 and 2025 (Level 4/5 = “Full self-driving automation”).

FIGURE 26 | Robots Don’t Come Cheap



Source: Ad Punctum Research, Delphi

FIGURE 27 | Rise Of The Machines



Source: Delphi

NOTE: “Full self-driving automation” is Delphi’s verbatim characterisation of Level 4 and 5

Delphi see the cost of the new technologies that enable driverless vehicles adding up to between $5,000 to $5,500 in 2020. That is for a first-generation system with limited economies of scale. Note that these figures are cost to the carmaker and the retail price would be higher. Their envisaged system is as follows:

- Six Cameras (vision sensors) -- at about $35 - $40 each
- Five radar sensors -- at about $65 - $70 each
- Four LIDAR sensors -- at about $500 each

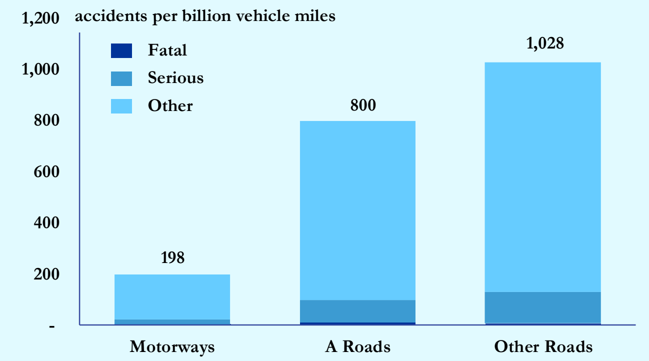
By talking in terms of Level 4 and 5, Delphi have hedged their bets about the competence of driverless cars in the early 2020 timeframe. The key difference between Level 4 and 5, as defined by the SAE (US Society of Automotive Engineers), is that a Level 4 car is only fully driverless in "some driving modes". For the business case of commercial on-demand driverless vehicles to work, they must dispense with the driver. In practice, Level 4 could mean that the car can drive on some roads but not on others. Delphi are therefore saying that the technology will be ready for the car to drive itself (Level 4) but it isn't clear whether the cars will be clever or experienced enough to deal with all road conditions (Level 5).

Some types of road are harder to drive on than others, as humans have proved. **Figure 28** a chart of UK accidents involving cars in 2015 by the type of road. This shows that Motorways (highways) are safer than A Roads (major roads but sometimes only single carriageway), which in turn are safer than other types of road (minor roads). Other data (not on the chart) shows urban roads have more accidents per mile travelled than rural roads (perhaps not surprising given the relative population densities).

Logic suggests that driverless vehicles will be capable on the easiest types of road first, and this is what practice suggests. Tesla's Autopilot (not a fully autonomous system) was rolled out on major roads first and the same will be true of both GM's Supercruise (which will partly rely on data created by a scouting fleet of cars traversing the most popular roads) and Volvo's intended self-driving system. **Figure 29** shows the amount of road in the EU28 by road type.

FIGURE 28 | Safety Matters

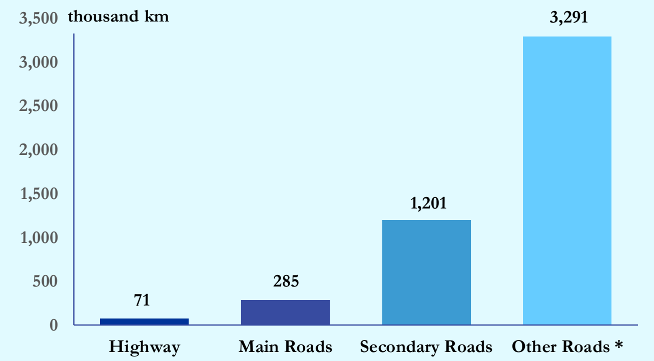
UK ACCIDENTS INVOLVING CARS IN 2015
BY ROAD TYPE AND SEVERITY



Source: Ad Punctum Research, UK Department for Transport

FIGURE 29 | Other -- The Colossus Of Roads

LENGTH OF ROAD NETWORK IN EU28 COUNTRIES
BY TYPE OF ROAD



Source: Ad Punctum Research, European Commission

At first sight, there are grounds for concern. The clear majority of the road network is on secondary and other roads -- the hardest type for the vehicles to learn how to navigate. It is this statistical distribution of road network length that lies behind many people's intuitive feel about the development of driverless systems. It goes something like this:

1. Driverless vehicles will take a long time to become good enough to handle the most difficult driving situations
2. The most difficult driving situations normally appear on smaller roads and where there are people around
3. There are more small roads than main roads
4. Given all the above, it will take a long time for self-driving vehicles to master the road network and until that time, humans will continue to drive themselves

The flaw in this line of reasoning is the third step. Whilst it is true that the road network contains far fewer main roads and highways than other road types, this is not a reflection of usage. **Figure 30** shows the distance travelled on roads in the

NOTE: [Fig. 29] The definition of road types varies from country to country, the data are therefore not comparable. 'Other roads' sometimes includes roads without a hard surface.

USA and UK by the type of road. This shows that around 70% of travel is on major roads -- which driverless vehicles are already capable on (or soon will be).

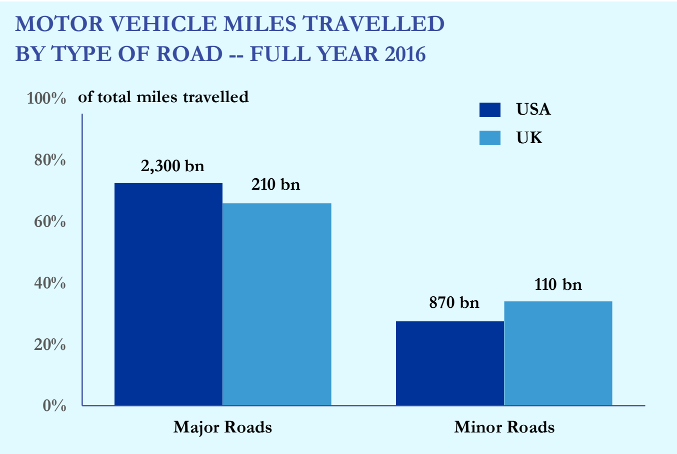
Driverless cars do not need to be capable on all roads immediately. The vehicle can choose a route that avoids unfamiliar roads -- taking the long way around if necessary (the customer mustn't feel overcharged). The artificial intelligence will then increase familiarity one road at a time on a cost-benefit basis (cost of scout cars driving the route to learn it versus extra revenue from knowing the road). This initial application of driverless commercial services could work as follows:

1. People will order ride hailing cars from the likes of Uber, Didi or Lyft as they do today
2. They will be asked to opt in to the possibility of having a driverless vehicle (perhaps in return for a discount)
3. If the algorithm determines that their route can be accomplished through roads that a driverless vehicle can navigate then they will be sent that vehicle.
4. If not, a vehicle with a human driver will turn up, as it does today (perhaps with a load of extra kit on the roof so it can act as a scout car and help build the map of roads driverless cars aren't yet released onto).

This type of approach -- determining safe roads and driverless-capable routes -- is known as "geo-fencing" and can be done alongside city planners to give them control over the process and comfort with the decisions made. The vehicle will be told via its GPS co-ordinates and mapping data not to use certain roads. This could even be changed dynamically. For instance, driverless vehicles can normally use road A, but are excluded when roadworks reduce it to a single lane.

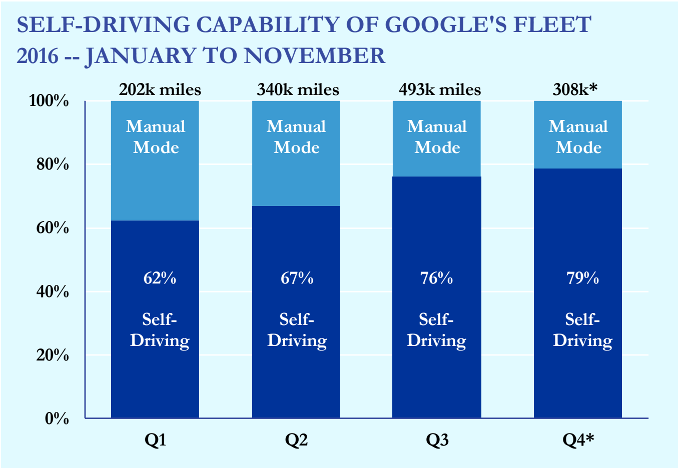
The timeline for self-driving capability is still unclear and there does not yet appear to be any definitive amount of time that a system takes to learn a road network (for instance, crash reporting data indicates Google's fleet are spending a lot of time in the same postcodes even though they've driven those streets many times before). The foremost advocate for widespread autonomy is Tesla. Without giving concrete commitments, they have offered the prospect of fully automated driving very shortly. There are others who believe that the technology won't be ready before the late 2020s. **Figure 31** shows data reported by Google about the performance of its self-driving fleet during 2016.

FIGURE 30 | The Road Less Travelled



Source: Ad Punctum Research, Federal Highway Administration, Department for Transport

FIGURE 31 | Machine, Learning



Source: Ad Punctum Research, Google

Figure 30 suggests the pessimists will be proved wrong. Many carmakers will launch systems that give autonomous travel on major roads by 2020, among them Tesla, Nissan, PSA and Volvo. This will bring over 60% of miles travelled within the capability of self-driving vehicles and from there the industry can concentrate on the roads that it has yet to master. If this line of reasoning is correct, the advent of self-driving vehicles will be nearer-term than many believe -- a large proportion of autonomous travel will be possible by 2020. Capability would therefore exceed demand. Actual rates of uptake will be driven by the compelling business case and by regulators. We see three steps in the switchover to autonomous technology:

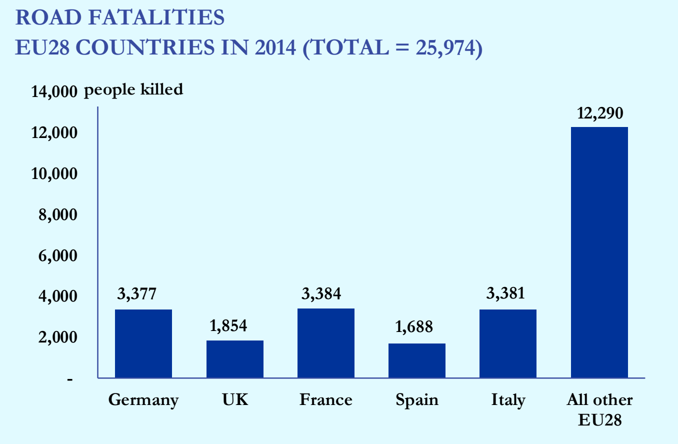
1. **Pilot** -- Sometime around 2020 several major trials will be launched by different operators. These will have varying degrees of success. Those using an integrated fleet of human drivers and robo-taxis will likely make the greatest progress. These schemes will prove the business model, show how quickly customers are willing to adopt and demonstrate the rate at which vehicles can learn the local roads. At this point the fleets will still be relatively small and

NOTE: [Fig. 31] Google stopped reporting figures in November 2016, so Q4 is incomplete so will not be confronting the capacity challenge that has been described in this report. Pricing will be in line with human-driven taxis, thus highly profitable since costs will be near to $0.60 per mile. With a favourable regulatory and consumer attitude, this phase could last less than 24 months.

2. **Gold Rush** -- Leading companies will start an arms race to roll out self-driving fleets that cover all travel needs. Different methods will be tried out to ease the transition for the private car owner, possibly by offering automated vehicles that have a manual driving mode to make customers feel comfortable that they won't be stranded in an emergency after opting for a robo-taxi subscription. Companies will aim to move people out of vehicle ownership but the solutions will reflect the limitation of the vehicle to be able to drive in 100% of conditions -- the fleet might be expected to operate well above 90% of complete trips in fully autonomous mode. It is possible that this phase takes place before 2025 since the technology will operate reliably over such a wide range of customer journeys in that timeframe. Production capacity could be a constraint.
3. **Maturity** -- Consumers see miles-travelled plans as preferential to vehicle ownership (a small minority continue with their own vehicle). Clearer eco-systems emerge as companies learn what is within their core competence and what they are best to outsource. Price competition and cheaper technology pushes fares towards $0.50 per mile. Declining volumes in richer countries cause problems for carmakers. This could be aggravated if there is a significant divergence in product portfolio between rich and poor countries (reducing economies of scale).

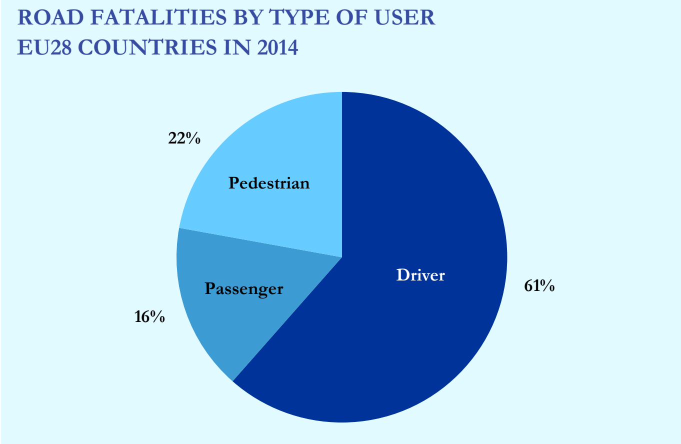
Why will regulators encourage autonomous vehicles? Some won't, but many are likely to be attracted by the prospect of accident reductions. **Figure 32** shows nearly 26,000 people died in road accidents during 2014 in EU28 countries. Given that autonomous vehicles are widely expected to lead to a reduction in accidents of around 90%, far fewer people would be killed if human drivers were removed from the roads. Once the safety of self-driving vehicles has been established, it is possible that regulators could go even further and in time remove manually driven vehicles from the road (probably not a realistic prospect any time soon). **Figure 33** shows that almost 40% of those killed are passengers and pedestrians, so regulators might not be sympathetic to drivers protesting their fundamental human right to drive vehicles.

FIGURE 32 | The Human Cost



Source: Ad Punctum Research, European Commission

FIGURE 33 | Care Needed



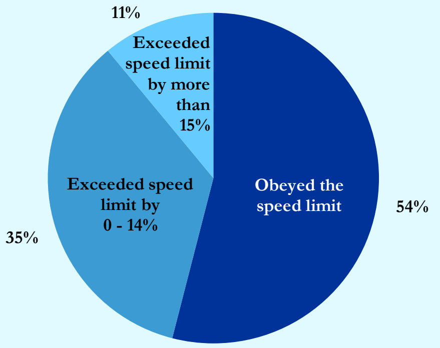
Source: Ad Punctum Research, European Commission

The unfortunate truth is that human drivers have many flaws. They don't pay attention properly and they misjudge risks. One of the criticisms levelled at self-driving cars is that they drive too slowly, sometimes likened to "elderly grandmas". While some of this is down to the immaturity of the programming, in many cases it is simply that humans drive too fast.

Figure 34 shows what regulators already know -- people don't like being told what to do, even if the primary motivation is safety (cynics will say motorway speed limits reflect fuel economy targets). In the UK, marginally more half of drivers obey the motorway speed limit. Regulators know something else. As **Figure 35** shows, people aren't as good at driving as they might believe. In the UK in 2015, half of all road accidents involving cars and vans happened when the vehicle was travelling in a straight line (according to the accident report). 20% were when the vehicle was coming to a stop, waiting or beginning to move off. These statistics point to the role that lapses in concentration play in so many accidents -- something regulators will be keen to improve upon with autonomous or semi-autonomous technologies.

FIGURE 34 | Speed Demons

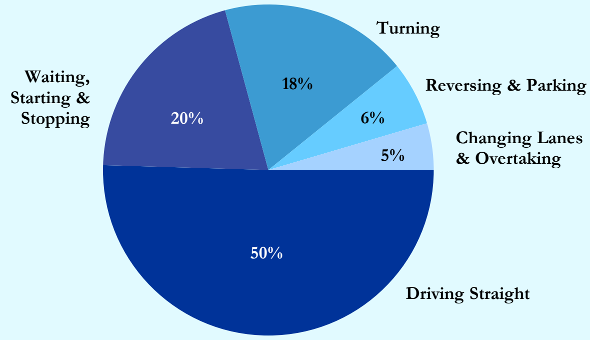
OBSERVANCE OF MOTORWAY SPEED LIMIT IN THE UK
2015 DATA, UK SPEED LIMIT = 70 MILES PER HOUR



Source: Ad Punctum Research, Department for Transport

FIGURE 35 | Only Human

ROAD ACCIDENTS INVOLVING CARS & VANS
BY TYPE OF MANOEUVRE -- UK IN 2015



Source: Ad Punctum Research, UK Department For Transport

Current real-world examples suggest that regulators can keep pace with the capability of technology and feel comfortable in their assessment of the overall risk management structure of individual companies. The safety benefit of driverless vehicles is already being demonstrated -- even with small test fleets. For example, the California Department of Motor Vehicles publishes records of all accidents involving autonomous vehicles, regardless of the nature and cause of the accident. Between October 2014 and March 2017, 28 accidents had been recorded. Those reports indicate that one incident was the responsibility of the self-driving car, one was inconclusive and the remainder (over 90% of the total) were all because a human driver crashed the autonomous vehicle in manual mode or were the fault of the other party.

Although regulators have an incentive to favour autonomous vehicles, this doesn't mean that they will be pushovers. In California, some companies have been allowed to run driverless cars for several years, but the Department of Motor Vehicles has shown itself prepared to place restrictions on companies that it believes have further work to do.

The automotive industry is presently working on the assumption that self-driving software is a key differentiating piece of IP but regulators may take a different view. They could demand far more open access, data sharing and even editorial control than companies anticipate. This could result in myriad different technical standards by region and the possibility that the winning technologies are not those that are best, but those that first won approval from a significant regulator. If safety remains as the prevailing governmental and regulatory impetus for driverless vehicles then expect serious accidents to result in demands for best practice sharing and common standards, as in the nuclear power and airline industries.

What about the consumer response? Although in many regards this is one of the least studied areas so far, anecdotal feedback from public encounters with driverless vehicles is overwhelmingly positive. Concerns that the experience will be too creepy or the car won't be capable of driving are quickly dispelled. Although cynics say this is a function of these events only taking place under vetted conditions, it reflects industry and regulatory reluctance to move too fast on autonomy. For good reason, they are only letting people try the technology when it is well polished and will continue to follow this philosophy as production reality nears. Evidence from Tesla Autopilot and Mercedes-Benz S-Class owners is that once presented with autonomous technology, people are prepared to take outrageous risks whilst enjoying its benefits (e.g. filming the car drive itself from the back seat on a camera phone instead of concentrating on the road).

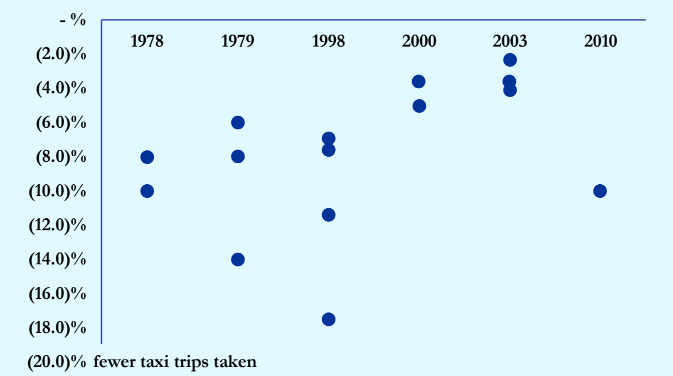
The key motivating factor for the consumer will be price. Research into the taxi industry stretching back decades (summarised in a 2014 research paper) helps to quantify relationship between lower prices and increased usage. **Figure 36** shows a summary of various research papers that investigated the impact of fare increases on taxi trips. Universally, the impact is negative (as would be expected). At first sight, it looks as if there is a significant difference. This in part reflecting that impact varies by customer type (business travel versus commuting) and by need (peak versus off-peak). However, the elasticities observed are all in a similar range in terms of order of magnitude. They are linear rather than exponential.

Figure 37 shows the relative impact of price, travel time and waiting time. This shows that the price paid is a more significant factor than the quality of the service. This also has implications for services such as UberPool where trips are longer because of other passengers. Since these studies are for shifts in price of a few percent, not fares falling to $0.60 per

NOTE: The 2014 paper is by Rose J and Hensher D. Titled "Demand for taxi services: new elasticity evidence". The full reference is in the Acknowledgements and sources of data section.

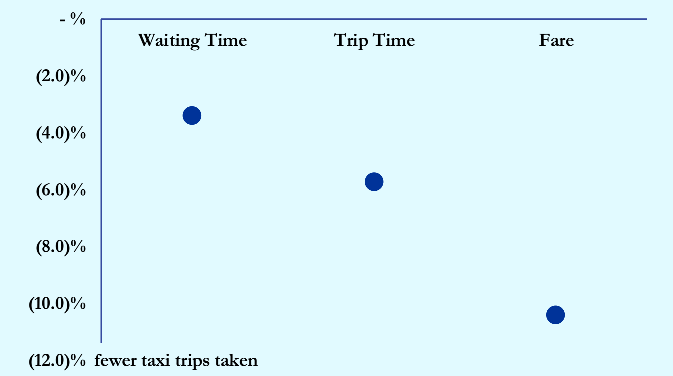
mile from around $4.00 per mile, it is fair to suggest that the research created so far may not be conclusive about the effect of ride hailing price competition on travel habits.

FIGURE 36 | Not So Very Different



Source: Rose & Hensher (2014), Ad Punctum Analysis

FIGURE 37 | Price Over Quality



Source: Rose & Hensher (2014)

At $0.60 per mile the private car owner will be offered a compelling proposition: pay less for a service that gives you more than you get today (i.e. you can do something else other than driving). Some will say that they enjoy the thrill of driving and will never give it up and this will be true, they won't. Just as there are some people who have never given up horse-riding. Their experience however demonstrates the following:

- The number of people continuing to do horse riding is a small subset of the population (about 2% of the UK population are judged as regular riders -- 1.3 million people)
- The number using horses for travel is a far smaller subset of that already small group (virtually nil)
- The asset base (i.e. the number of horses) -- is less than one per regular rider (this figure includes race horses and the like) indicating widespread sharing, even among enthusiasts
- The switchover from horse to motor vehicle was rapid -- although definitive figures for how the horse population changed as vehicle usage grew are hard to find, indications are that London's horse population used for transport fell from around 300,000 to virtually nil between the years of 1900 and 1914

Although data about public reaction to autonomous vehicles is hard to come by, there are some examples of completely driverless vehicles (An Uber test vehicle where a "safety driver" and engineer occupy the front seats doesn't feel driverless to us). At present these real-world experiences are focused on bus-type applications. Examples include the following:

- ParkShuttle in Rotterdam, Netherlands has been operating for 13 years and carries around 1,200 passengers per day
- NAVLY shuttles in Lyon, France have been on trial carrying around 400 passengers per day

Admittedly there are some human touches added, such as the presence of a conductor in the NAVLY vehicles. They do not have any driving responsibility but can explain the service to passengers.

Peer-to-peer sharing of privately owned vehicles is one possible way to lay the foundation of an autonomous vehicle fleet. Although this seems a neat solution, it faces three substantial challenges:

- **There won't be many peer-to-peer vehicles available.** A driverless system costing between $5,000 - $10,000 is only affordable for consumers at the upper end of the wealth spectrum -- a subset of premium car buyers.
- **Carmakers will be reluctant to put the technology into the hands of private owners for many years.** Figure 27 (Delphi's adoption forecast) had separate lines for commercial and retail customers for a reason: carmakers will find it hard to trust retail consumers to keep within the technical constraints of driverless mode. In effect, they need to find a balance between ease of use and safety. Locking the system down remotely means usage becomes cumbersome and unpredictable (and depresses the price customers will pay). Giving customers free rein to use the technology in circumstances where it is not capable leads to abuse (those videos by Tesla and S-Class owners attest that this is a real

problem). A commercial fleet owner will take the legal implications of ignoring manufacturer guidance more seriously. Most manufacturers will therefore feel comfortable selling to commercial operators some time before they are prepared to put the technology into private hands (which could impact the used market).

- **Driverless vehicle owners will want too much money to share their vehicle**. The path to a $0.60 per mile fare is underpinned by a commercial logic of using the vehicle until the end of its life to provide a reasonable service and amortising this cost equally across the miles travelled. The problem with this in a peer-to-peer circumstance is twofold: (1) owners of private driverless vehicles won't be looking to run their vehicles to the end of life, they will still want to renew every few years -- especially true of premium car buyers. This "inefficiency" must be paid for. (2) people attach an emotional value to letting somebody share "their" asset, as well as wanting recovery for the very real effects of depreciation from additional mileage and wear and tear 3rd party usage brings. If an owner released their vehicle for a "profit" of $0.50 per mile (i.e. they would get a contribution for depreciation and fuel on top of this) over 1,000 miles per month, they would make $6,000 per year in return for doubling the usage of their vehicle. Will that be significant for someone already rich enough to buy a premium car? They would also put themselves at risk that sometimes the vehicle would be in use by 3rd parties when they needed it in an emergency (functionally, they could always summon someone else's car but emotionally it wouldn't be the same).

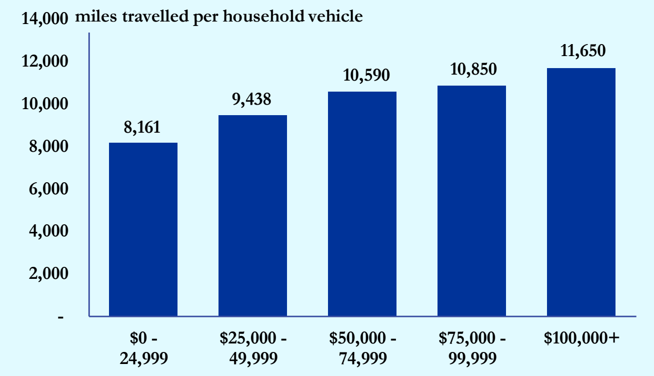
The carmaker could increase take-up by discounting the cost of the technology on condition of joining the peer-to-peer scheme. They would get a fatter share of scheme profits and have greater control over what conditions the vehicle was in automatic mode. This could be an elegant approach but will still face challenges to get vehicles widely released -- a fully commercial vehicle could be usefully employed for between 70,000 and 130,000 miles per year. Private owners may well struggle emotionally to agree with using their car more than they do (on average about 10,000 miles each year). Manufacturers must also resolve the issue of second-hand ownership -- can used buyers be forced to continue on the same terms? Do used vehicles participate in the program or does the first cycle pay for itself (increasing depreciation per mile)?

The outcome is that peer-to-peer schemes likely have higher fares than the $0.75 cents per mile that private car owners pay today. First, for the additional equipment, secondly for the owner's premium and thirdly for the scheme operator's costs and profit. Although some people may choose this peer-to-peer scheme over car ownership, the $0.75 per mile is a very real cost barrier. Many people simply cannot afford to pay more for their travel regardless of how cool or relaxing the idea of having someone else do the driving is. Therefore, schemes charging over $0.75 per mile will have limited appeal.

Why do we insist on the $0.60 to $0.75 per mile range as some sort of tipping point? It is because of research looking at how much people use their cars as costs change. A 2014 research paper titled "Impact of fuel price on vehicle miles traveled (VMT): do the poor respond in the same way as the rich?" utilised data from the 2009 US National Household Travel Survey to evaluate price sensitivity. This paper built upon earlier work investigating long and short term reactions to fuel price changes for the total population. **Figure 38** shows that poorer households on average drive fewer miles than rich households (the poorest drive 30% less distance than the richest). **Figure 39** shows (via translation into a real-world example) how different income groups vary in their sensitivity to price increases.

FIGURE 38 | I Am Considerably Richer Than You

MILES TRAVELLED BY INCOME GROUP IN THE US SUBSET OF 2009 NATIONAL TRAVEL SURVEY DATA



Source: Wang & Chen (2014), 2009 National Household Travel Survey

FIGURE 39 | Cutting Back

PERCENT REDUCTION IN MILES TRAVELLED FOR A 10% INCREASE IN FUEL PRICE

Source: Wang & Chen (2014), Ad Punctum Analysis

NOTE: The 2014 paper is by Wang T and Chen C. titled "Impact of fuel price on vehicle miles traveled (VMT): do the poor respond in the same way as the rich?". The full reference is in the Acknowledgements and sources of data section.

The consumers reflected in this analysis are all car owners, therefore they all have access to travel at a cost of around $0.75 per mile or lower (if they have a used vehicle which is reliable and frugal). The research therefore demonstrates price sensitivities to movement of just a few percent around the $0.75 per mile level. Although not conclusive, the implication is that only those in the top two income quintiles can afford to vary their travel to a significant degree because of price or other factors. The 3rd and 4th quintile appear to stick to the same level of travel regardless of price (indicating that they are close to what they regard as their non-discretionary level). The poorest group simply travel less when price increases.

This research, combined with the studies into taxi price elasticity, suggests that the market for ride hailing services will increase as prices are lowered -- in line with the growth that companies such as Uber and Didi have experienced. However, the elasticity will be linear, not exponential. From taxi services' share of travel today -- about 1% -- ride hailing in rich countries will not climb beyond low single digit percentages without driverless vehicles. A fair challenge to this assumption could be made on the basis that the available research has studied smaller percentage reductions in price than are under discussion here and the elasticity relationship may not hold under extreme price movement. This remains to be seen.

Adoption Scenarios

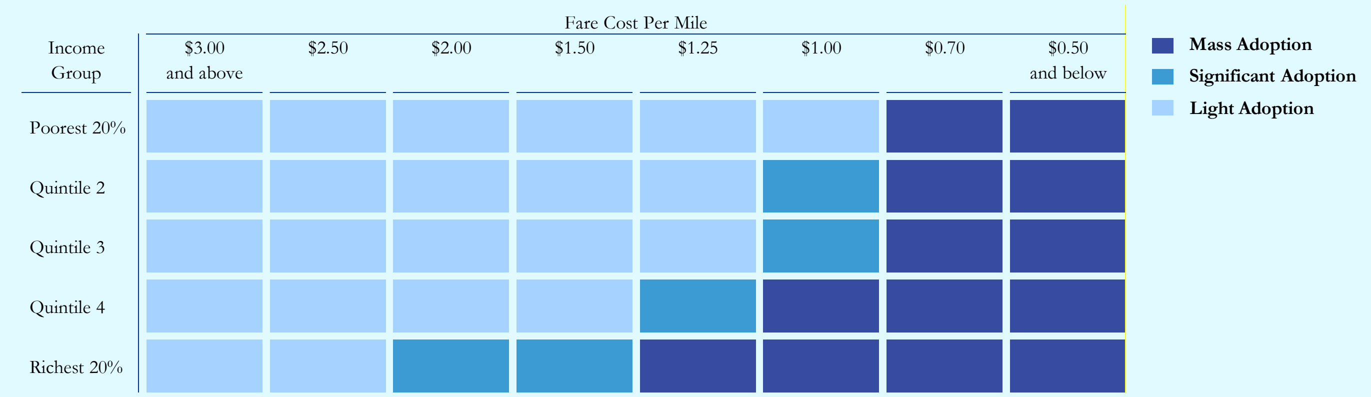
The preceding discussion points have identified a range of variables to use in scenarios for driverless adoption.

- **The ability of the sensor set to understand road conditions** -- as Figure 26 (the sensor set cost walk) showed, the technology cost in the 2020 timeframe is forecast to be around $5,000 to the carmaker. Scenarios include different starting costs (between $5,000 and $10,000) and different rates of cost improvement. Different capabilities could be assessed but, so far, we haven't seen indications that there are concerns in this respect (outside of extreme weather conditions). The constraints to real-world use seem wholly within the artificial intelligence side.
- **The ability of artificial intelligence to make decisions** using data collected by the sensor set is a topic of greater debate. The number of roads that driverless artificial intelligence can competently operate on is the best proxy for "ability". We see this as coming in defined steps: (1) familiarity with major roads, which would give coverage of around 60% of miles travelled; (2) familiarity with the most widely used minor roads, taking coverage to over 90% of miles travelled and; (3) sufficient data to give effective coverage of 100% of trips. Likely scenarios of capability range between 50% and 75% of miles travelled in 2020 (note that this is different to % of the road network) and then faster and slower rates of learning to near 100% capability (somewhere between 2030 and 2040).
- **Regulatory acceptance** is likely to vary in two degrees: (1) whether regulators encourage driverless vehicles because the accident reduction is so compelling or adopt a conservative approach on the basis that a higher accident rate is preferable to letting computers make life or death decisions and; (2) whether regulators build on collective global experience to create operating rules or work country-by-country (some are likely to remain reluctant to allow driverless vehicles onto the road even as they prove themselves capable in other territories).
- **Consumer acceptance** is likely to be either neutral (determined purely by price elasticity) or reluctant (even as price is reduced, some of the market is not prepared to use a driverless vehicle). The likely cause of reluctant rather than neutral acceptance would be a number of high profile accidents.
- **Investor enthusiasm and production capacity** must also be considered. Putting a fleet of millions of cars on the road will be an expensive proposition -- $50,000 per car for a fleet of 50 million vehicles (close to Scenario 3 in Figure 24) requires investment of the order of $2.5 trillion. It then requires an ongoing expenditure of hundreds of billions of dollars each year to sustain this fleet. Given that the global airline industry -- a business that has been around for decades -- has a balance sheet of somewhere between 500 billion and one trillion dollars; creating the financial innovations that support a driverless vehicle fleet tens of millions strong, as quickly as it needs to grow, could be a considerable challenge. So too will be the rate at which production capacity is added. If the driverless cars have little in common with traditional cars, this will take longer to put in place.

While fares are significantly above today's weighted average travel cost ($0.70 per mile), on-demand mobility will only have a small market share, catering to the top 40% by income level (irrespective of whether services use autonomous vehicles or human drivers). As the price nears $0.70 per mile, demand will grow substantially. **Figure 40** illustrates this in a qualitative way.

FIGURE 40 | When Will You Love Me?

QUALITITATIVE ON-DEMAND ADOPTION ASSESSMENT BY INCOME GROUP ASSUMING MIX OF COST AND QUALITY OF SERVICE FACTORS



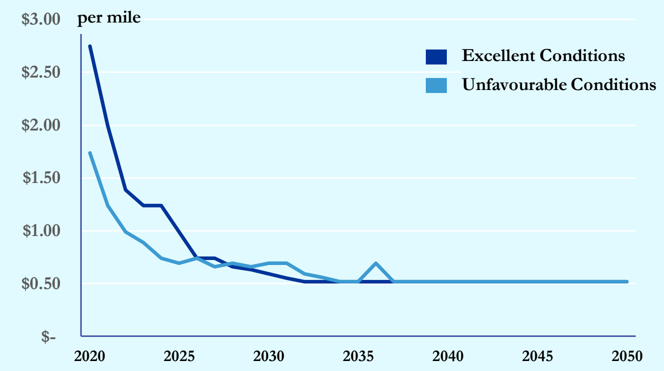
Source: Ad Punctum Research

The assessment above is solely related to fares charged (operator revenue). The cost walk in Figure 17 demonstrated the hypothesis that, at sufficient scale, a driverless service would have low enough operating costs to return a profit with fares at $0.60 per mile. Operators will face a choice: should they offer their lowest possible fare or price more closely to the cost of a human driven taxi? Logic suggests that they set prices as high as they can. Whilst capacity is small, the price will be close to traditional taxis and ride hailing, profits will therefore be huge. As capacity builds, prices will tend towards the minimum profitable operating cost -- calculating the rate of change necessitates the creation of a bid/ask model that can assess the market price for a given driverless vehicle capacity.

Resolving two scenarios through a bid/ask model -- one highly favourable (low cost, high capability, favourable regulators) and one unfavourable (technology is still capable but takes longer to generate trust) gives an idea of how outcomes may vary. **Figure 41** shows how fares would change and **Figure 42** shows how the share of private road transport would grow

FIGURE 41 | What Is It Worth?

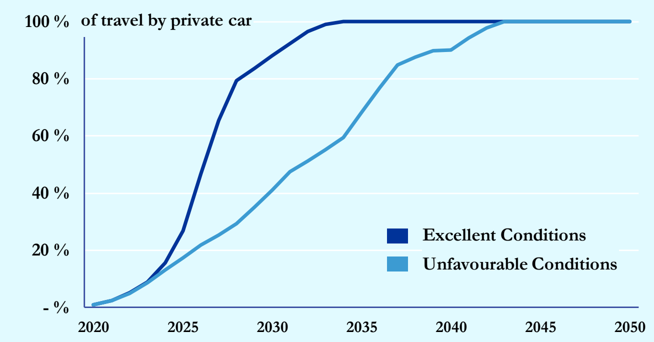
PER MILE REVENUE FROM ON-DEMAND MOBILITY FOR DIFFERENT ADOPTION SCENARIOS



Source: Ad Punctum Research

FIGURE 42 | Off Like A Rocket

ON-DEMAND MOBILITY SHARE OF PRIVATE TRAVEL GROWTH RATES IN DIFFERENT ADOPTION SCENARIOS



Source: Ad Punctum Research

At first sight, Figure 41 seems counter-intuitive: why would the Unfavourable scenario create lower prices? The answer is that the cost of profitable operation, at around $0.60 per mile, is substantially below initial revenues in any case. The operators are having to lower prices because of public reluctance to use the service. In the Excellent scenario, robo-taxis have stronger pricing power relative to human-driven taxis and this allows the operators to reap higher surplus profits.

Intriguingly, regardless of favourability, these scenarios suggest the business can grow organically from cashflow -- providing an initial investment of a few billion dollars is made. Although may stretch intuition, a business operating at $0.60 per mile that can price near to a human driver's fare of over $2.00 per mile generates a tremendous amount of cash. This can be ploughed into fleet expansion and due to high profits, initial fleet investments have very short payback periods.

In both scenarios, the price ultimately falls to around $0.50 per mile as the price matures, reflecting the falling price of the vehicle. Even if the sensor set is $10,000 in 2020 and development is relatively slow it will be substantially cheaper by the mid-2030s. This price can still support 15% profit margins, given the reduced input costs.

Figure 42 shows a considerable difference in adoption rate. **In the Excellent scenario, adoption approaches 90% by 2030** through a combination of AI ability, a relaxed regulatory approach and consumer reaction to the low prices compared to private vehicles ($0.60 per mile versus $0.75). The growth is a classic S-shaped adoption curve.

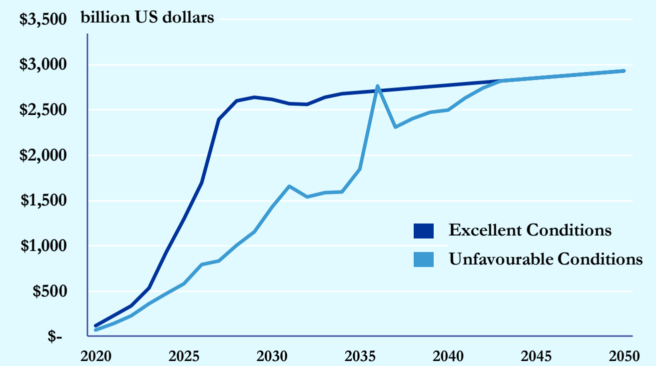
Even in the Unfavourable scenario, share of journeys in 2030 is around 40%. Although this is substantially below the Excellent scenario it is above many forecasts made by third parties. The cost advantage of autonomy is simply overwhelming. As soon as they reach any significant level of capability, autonomous vehicles aggressively take share from private vehicles. At this price, customers will be happy to help the system to build capability. For instance, from time to time it may be necessary for the driver to complete the last mile. With an appropriate handover process (probably involving the vehicle stopping and a pause whilst the human driver takes control), the journey can still be door-to-door and afterwards the vehicle can return to autonomous usage. Another possibility is that operators in call centres could take control of vehicles where the AI is overwhelmed. Nissan have already demonstrated such a scheme.

The Unfavourable scenario is not the worst-case. It assumes that autonomous vehicles appear in 2020 and the market can develop organically, albeit impeded by a sceptical customer base and burdensome regulatory requirements. A worst-case scenario would push introduction timing back and would include plateaus where regulators became over-stretched by the burden of assessing autonomous vehicle safety.

In practical terms, Figure 43 shows that for the US market this leads to revenues of around $3 trillion in the early 2040s. The profit picture is similarly inviting -- Figure 44 shows annual profits of over $350 billion in the same timeframe. Both scenarios assume the same increase in miles travelled, about 20% from today's conditions. With different travel growth scenarios, the shape of the graphs remains but the absolute financial return would vary.

FIGURE 43 | Big Business

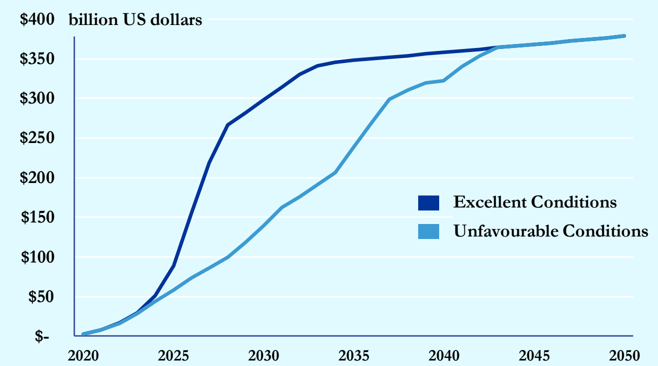
US REVENUES FROM ON-DEMAND MOBILITY FOR DIFFERENT ADOPTION SCENARIOS



Source: Ad Punctum Research

FIGURE 44 | Strong Returns

US PROFITS FROM ON-DEMAND MOBILITY FOR DIFFERENT ADOPTION SCENARIOS



Source: Ad Punctum Research

The bad news for carmakers: most of this profit and revenue is substitutional, not incremental. The scenarios above represent consumers choosing to carry out their current travel requirements through an on-demand service rather than by using privately owned cars. The revenues and profits relate to an all-in service. Therefore, any carmakers salivating at the prospect of a near $3 trillion US market should reflect that this includes the provision of insurance, fuel and servicing. It is not simply the revenue from vehicles. In fact, since the 2040 assumption underpinning these models is around $0.50 per mile versus the current level of around $0.75 for new cars, this represents a significant decrease in revenue (on an all-inclusive basis) versus provision of travel today.

Keen eyes will notice that Figures 41 and 43 show a price/revenue spike around 2035 in the Unfavourable scenario. This occurs because the driverless fleet has not built up sufficiently quickly to fulfil all demand that rising customer and regulatory acceptance creates. This temporary inequality in demand and supply allows operators to increase prices and fund the next stage of fleet investment. This could be smoothed through additional up-front funding by investors. We chose to leave the bid/ask output as-is to demonstrate the type of market dynamics that could arise. These are all scenarios after all! If we had been sent from the future this report might still have been written, but likely from a more comfortable chair by a swimming pool somewhere (funded by repeat lottery wins).

The adoption analysis confirms that far fewer vehicles are needed. A 2040 nationwide US fleet providing 4.8 trillion miles of travel at occupancy rates of 1.6, average travel speeds of 30 mph and utilisation of 50% where the vehicles have a lifetime of 500,000 miles (like Scenario 4 in Figure 24 and 25 where the impact on vehicle population and annual sales was assessed) requires a fleet of 23 million vehicles and a production rate of just under 8 million vehicles each year (the miles travelled are higher than for Figure 24 and 25 where constant 2014 conditions were applied). Therefore, **even with substantive market growth the required production capacity is far below current levels.**

In summary, from looking at the probable cost and capability of the sensors and artificial intelligence needed for fully autonomous vehicles, and then comparing this to likely customer and regulatory response (and using the substantial research into the effect of price on travel) it is possible to conclude the following:

- **Autonomous vehicles will be capable of most journeys sooner than many people think -- by the early 2020s.** The classic driverless test is a narrow urban road filled with perils but this is a rarity, not a day-to-day reality, for most journeys. Around 70% of travel in the USA and UK is on major arterial roads and highways -- the technology is nearly capable of this now. Driverless cars don't need to be capable on 100% of routes to capture share. The network will grow road-by-road, just like cable TV.
- **Widespread autonomy will be with us by 2030 -- accounting for at least 40% of mileage.** The rate of switchover depends on three things: price, technology and regulation. The rate at which taxis win share as price drops has been studied for many decades. Taxis win share slowly and it is only the rich who can afford to pay extra. If you look at it from Uber's point of view, growth seems meteoric but this is from a very low percentage of travel in taxis (about 1% of trips) to a larger but still very low percentage of travel via ride-hailing. Reaching cost parity with car ownership creates a dramatic consumer response. Favourable regulation and technology progress could double the rate of adoption (to over 80% in 2030). This level of growth may not require a colossal amount of upfront funding -- cash flow is hugely positive since revenue is still related to taxi services with human drivers (albeit with discounts) but costs are far lower.
- **Regulators have a substantial role in the rate of adoption.** It isn't sufficient for driverless cars to be good enough, they must also be legal. Regulators aren't in universal agreement on what is good and bad about "dumb" cars today; myriad different laws, technical standards and tax rates attest to that. Expect autonomous vehicles to create even more regulatory misalignment. The upshot will be that those who are favourable to driverless on-demand mobility, and control access to significant markets, may shape the fundamental industry model and technical standards. It may not be the "best" technical delivery of an autonomous vehicle that becomes widespread, it could be the one that was most convincing to those governing the streets of California, London and Singapore. A very likely manifestation is that successful operating models will be ones that regulators see as win-win situations. For instance, a fleet that is entirely battery-electric. They will also shape operating details such as how fast a vehicle can drive in certain circumstances (manufacturers will struggle to justify that their vehicles are fool proof in freezing conditions) and whether it is the passengers or a remote control centre that takes over the vehicle if the automatic systems fail.

4. Winning New Customers

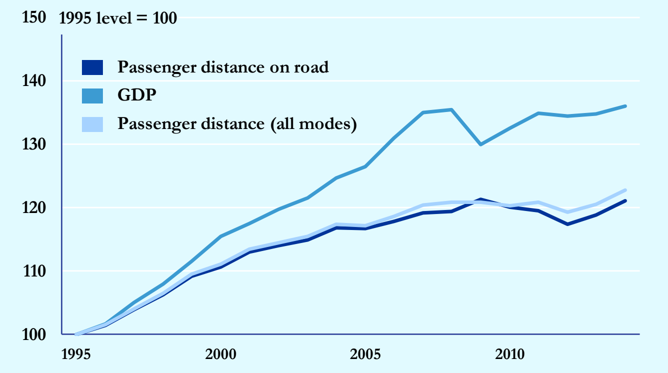
On-demand mobility can grow through four primary methods:

- Increased miles travelled, either through additional or longer journeys
- Taking share from private cars
- Taking share from public transport
- Enabling travel by groups who are under-served by today's methods

The good news is that growth in miles travelled is a virtual certainty. **Figure 45** shows the change in passenger miles (all travel types including air travel) and Gross Domestic Product (GDP) in EU28 countries between 1995 and 2014. Although not a match for the expansion in the size of the economy, passenger miles travelled have risen substantially. Most of this increase came from road transport (the dark blue line). **Figure 46** shows a future forecast from the UK's Department for Transport and reflects a range of GDP growth rates and market condition changes (e.g. fuel price). Even in the most pessimistic scenario (the light blue line), road traffic in 2040 is almost 20% above the level in 2010. In the most optimistic scenario (the dark blue line), it is 55% higher.

FIGURE 45 | Wheels Keep On Turning

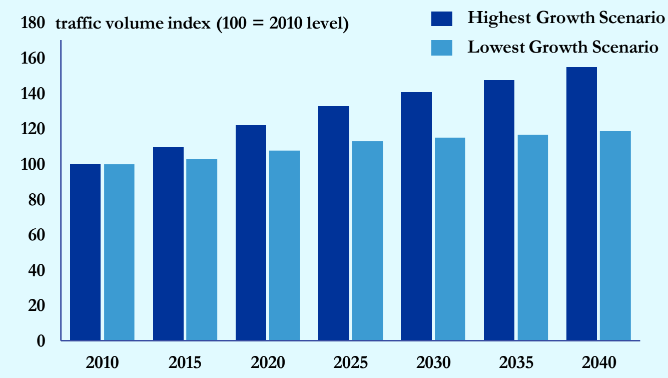
EU28 TRANSPORT AND GDP GROWTH BETWEEN 1995 AND 2014



Source: Ad Punctum Research, EU Commission

FIGURE 46 | Long May It Continue

UK ROAD TRAFFIC VOLUME 2010 - 2040 GOVERNMENT FORECAST SCENARIOS



Source: Ad Punctum Research, Department for Transport

On-demand mobility will primarily take share from private car ownership (taxis will be affected as well but their current market share is very small). As discussed earlier in this report, as the price nears -- and then breaches -- $0.70 per mile, travel will increasingly move to an on-demand service. As richer customers move to on-demand services, they will depress new car sales and therefore used car supply. This will have the effect of increasing cost for lower income groups as the price of used cars rise, encouraging them to move to on-demand services.

Evidence from car-sharing schemes (such as research in the USA carried out in partnership between Daimler and a university) suggests that customers abandon older used vehicles once they have reliable alternative means of transport. If this continues to be the case then car ownership could be eroded from the top and bottom at the same time. The result would be that owners sticking with new cars face price inflation due to the diminished demand in the used car market. This would push the cost of new car ownership above $0.75 per mile and encourage further migration to on-demand.

Taking share from public transport will be a substantial challenge. On the face of it, public transport should be fertile ground for an on-demand service. **Figure 47** shows the average commute time for different modes of transport in the US. Trips on public transport take substantially longer than those in a private vehicle even though the commuting distances are very similar (average of 12.1 miles for a private vehicle and 10.2 miles on public transport). Furthermore, public transport is expensive to provide.

Although point-of-use fares are far lower than vehicle usage (our earlier analysis shown in Figure 5 established bus and metro at just over $0.40 per mile), this is achieved through massive use of subsidy. **Figure 48** shows the state of funding of various public transport arms. In the USA, the average public transport agency (bus and metro) covers only around a quarter of its costs from fares. The agency responsible for running London's transport has income of 55% of its costs, but

NOTE: The 2016 UC Berkeley paper is by Martin E and Shaheen S titled "The impacts of Car2Go on vehicle ownership, modal shift, vehicle miles travelled, and greenhouse gas emissions: an analysis of five north America cities". The full reference is in the Acknowledgements and sources of data section.

this includes revenue from the congestion charge (in effect a toll). If fares were made to reflect running costs then, even for a systems with a relatively high income to cost ratio, they would be in excess of $0.75 per mile. An on-demand scheme with fares in the range $0.50 - $0.60 per mile would provide considerably cheaper travel on a total cost basis.

FIGURE 47 | I Haven't Got All Day

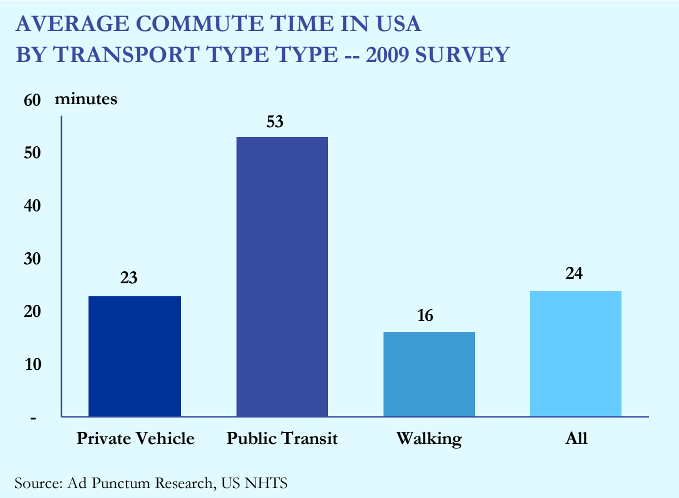


FIGURE 48 | Expensive Way Of Doing Things

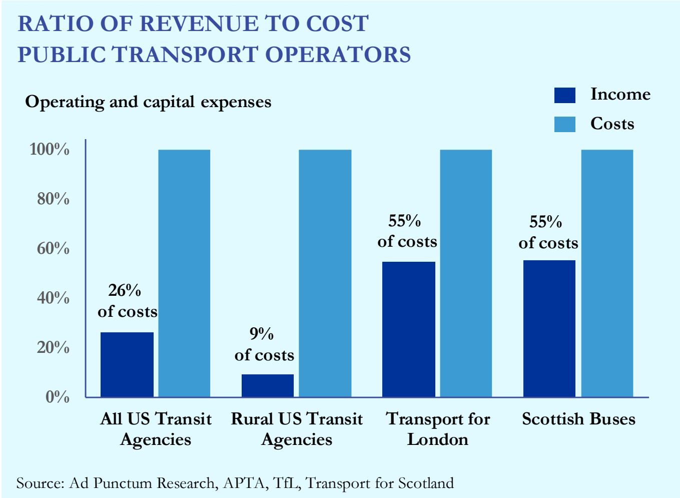
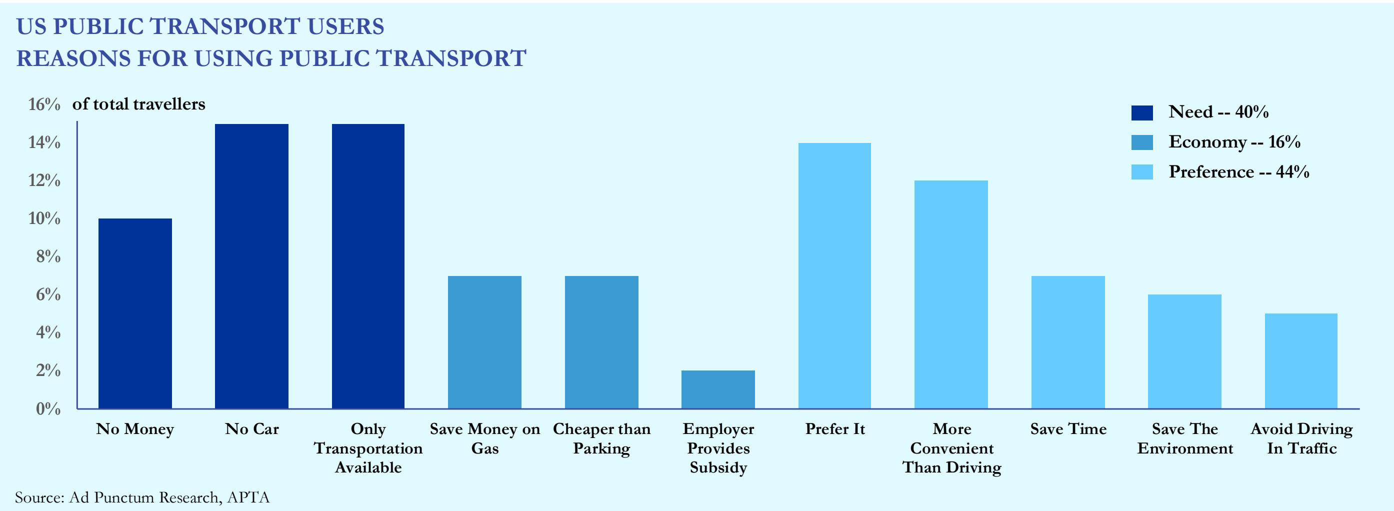


Figure 49 shows reasons for taking public transport given by users in the USA. Many users of public transport (over 40%) seem to choose it above driving on convenience rather than purely price -- even though this convenience comes at the cost of travel time as demonstrated in Figure 47. Driverless cars would be excellently placed to satisfy these customers.

FIGURE 49 | Why I Do What I Do



On-demand mobility faces a problem in competing with the visible point of use cost of public transport. Even though it really costs more than $0.40 per mile to deliver, this is how cheap public transport looks to its customers. Public transport is subsidised because there are many consumers who simply cannot afford to pay more for the travel (Figure 47 shows that they make substantial trade-offs in terms of time).

For on-demand mobility to capture these customers either costs must fall so that it is cheaper at the point of use or the subsidy currently directed at public transport could be given to on-demand mobility providers instead. A massive logistical challenge lies in the way of the latter scheme -- means testing.

Subsidising travel for all (the current practice) is expensive, but is simpler in application than the theoretically cheaper option of subsidising only those in need. Most public transport schemes have means-tested free or heavily discounted fares, but only for a small amount of the population (normally the elderly and those on very low incomes). Subsidies that are not targeted would increase travel cost for the poorest groups -- politically untenable.

Blanket subsidies (e.g. to lower the cost of all trips in a region by $0.05 per mile) could still prove too expensive (since it would cover the 80%+ of trips that aren't on public transport). Without some sort of breakthrough using big data therefore, the transfer of existing subsidies to on-demand schemes will be very rare, even where there is a theoretical "business case". Perhaps the same software innovations that allow near-real time approval of loans can be put to work for means-testing?

This is not to say that on-demand will fail to take share from public transport, simply that wholesale conversion is not assured until costs fall to around $0.40 per mile. Until that time, the half of public transport users who choose that method based on cost will be out of reach. Ways to lower cost to $0.40 per mile are discussed in the next section of this report.

The increase in travel by people with restricted mobility today is likely between 5% - 10%. Therefore, the contribution to market size of all these people being able to travel is useful, but not game-changing. In 2009, over 90% of the US population had a car in their household and access to transport at a marginal cost of around $0.75 per mile (driver availability permitting). **Figure 50** shows that many of the households without a vehicle seem to do so by choice -- they are clustered in areas with high population densities (i.e. cities). **Figure 51** shows a similar trend in England. **Figure 52** shows annual travel in England by age group.

FIGURE 50 | Living Without A Car

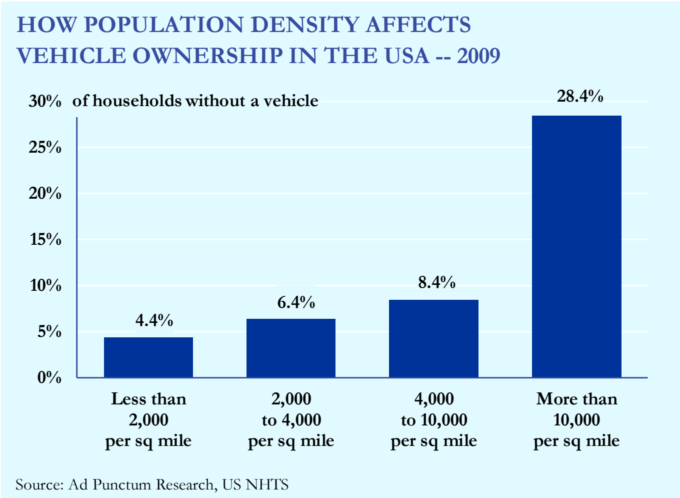


FIGURE 51 | More Of The Same

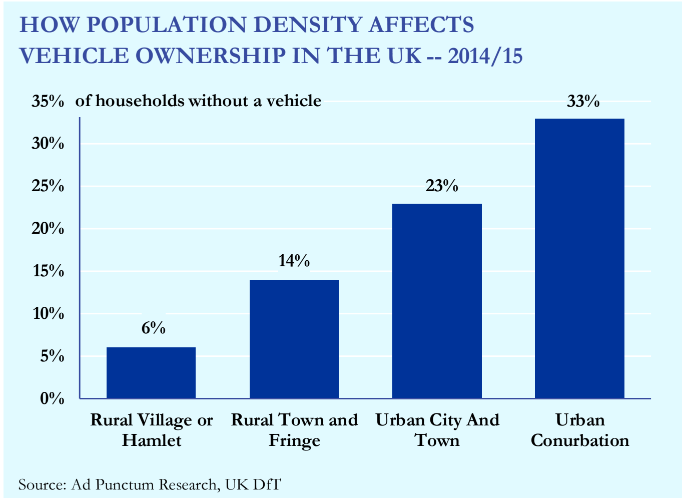
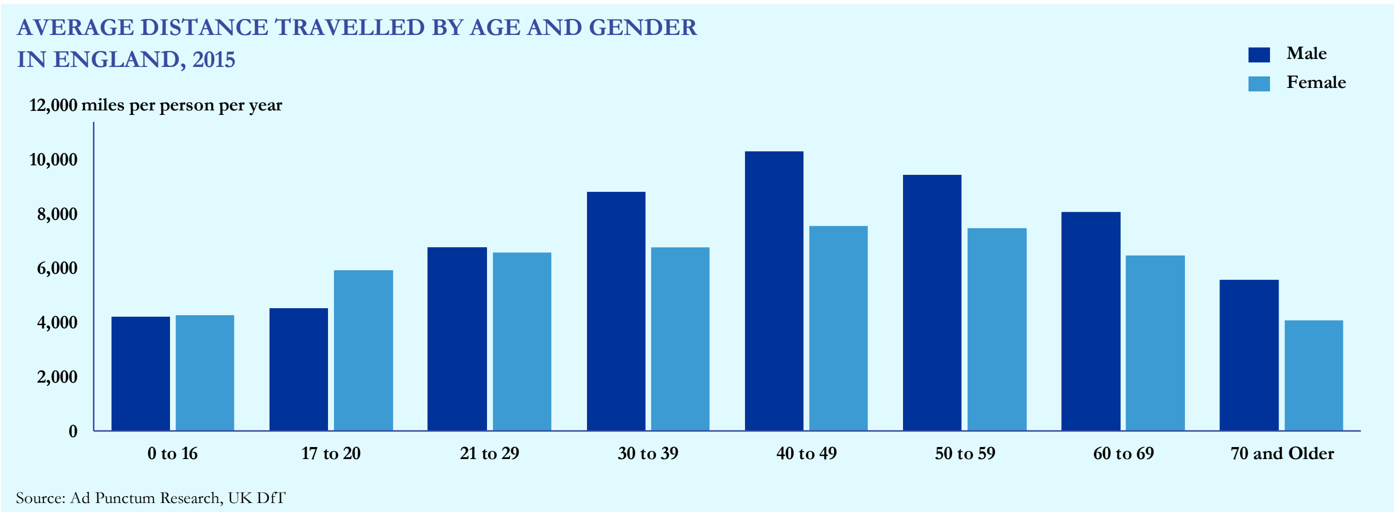


FIGURE 52 | The English Are Greatly Moved



As might be expected, there is greater travel amongst the working age population than the older and younger sections of the demographic. Could this be a sign of unfulfilled demand? To some extent, yes. The UK Department for Transport provides a variety of travel data that shows the amount and method of travel by different age groups in England. This

NOTE: [Fig. 51] & [Fig. 52] are for England only, not the UK
[Fig. 52] - US data from the 2009 National Household Travel Survey has a similar profile

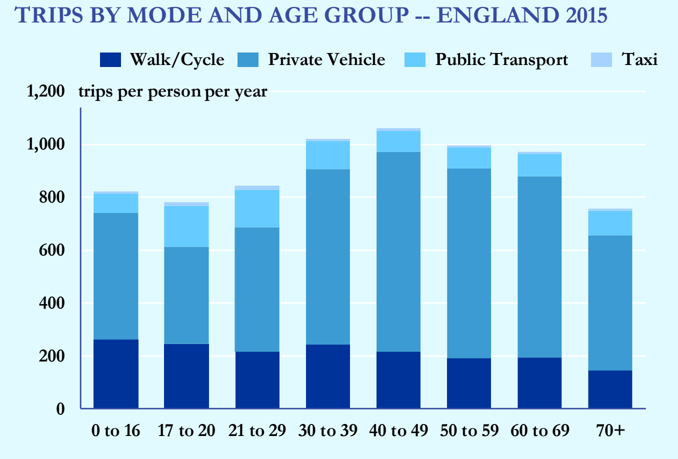
made it possible to evaluate some different ways of calculating the potential for travel to increase if it were easier and cheaper than today.

1. If people who walk less than average today use on-demand mobility to cover the same distance as the average walker
2. If the age groups with the lowest levels of travel in terms of trips make as many journeys as their closest "high travelling group" (i.e. All 0 - 29 year olds travel in future as much as 21 to 29 year old males do today and all people aged 60 and above travel as much as 60 to 69 year olds do today)
3. If those with mobility difficulties today (representing around 9% of the English population) make as many trips as those without (which would represent around 40% more journeys for those affected)
4. If the age groups with the lowest levels of travel in terms of distance start to cover the same level of mileage as their closest "high travelling group" (i.e. All 0 - 29 year olds travel in future as much as 21 to 29 year old males do today and all people aged 60 and above travel as much as 60 to 69 year old males do today)

Figure 53 shows input data: the number of trips taken by each age group, and the transport method. The shape of travel against age profile is like Figure 52 but the variation between high and low travelling groups is less pronounced. Although it isn't completely clear from the chart, the mix of transport method is very stable (20 - 39 year olds use public transport much more than other age groups).

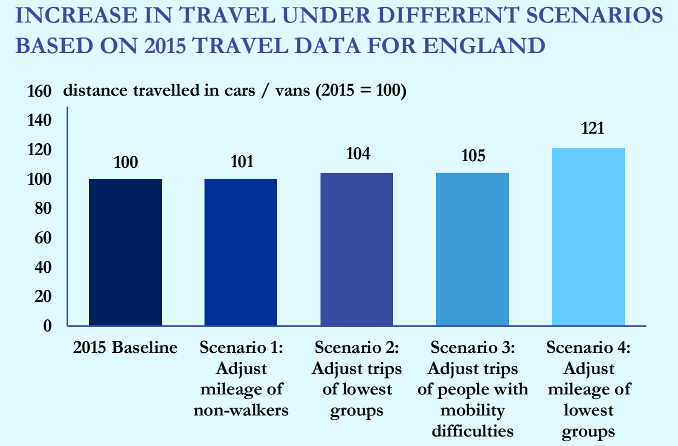
Figure 54 shows how the different travel scenarios might inflate the mileage of private vehicles versus today.

FIGURE 53 | I Like The Way You Move



Source: Ad Punctum Research, UK DfT

FIGURE 54 | Travelling More, More Easily



Source: Ad Punctum Research, UK DfT

Although scenario 4 yields an increase of over 20%, this seems like an unrealistic assumption since average distance per trip is lower for the outlying age groups (mainly because they don't commute). To align the mileage rather than trips would suggest that the underlying travel needs of these groups had changed rather than they were simply travelling more. Scenarios 2 and 3, which adjust for the shortfall in trips yield a near 5% increase in total mileage (there is a far greater increase for the affected groups but 5% is the effect across the entire population).

In summary, from looking at the cost structure and customer base of public transport and the way in which travel varies across the population, it is possible to conclude the following:

- **Autonomy will struggle to take public transport's 15% share whilst fares are above $0.40 per mile.** Once this level is reached, the 15% or so of public transport customers could switch. Public transport loses money but it keeps fares low at the point of use and more than half of its customers are price sensitive. Without an innovation that transfers the existing public transport subsidy to on-demand customers on a means-tested basis, they will wait for a lower fare level before switching.
- **The increase in travel from people less restricted than today is likely between 5% - 10%.** Increased freedom for those with restricted mobility will be welcome but will not substantially change the fleet mileage because they are a relative minority in the population and they already travel today (albeit less frequently than average).

NOTE: [Fig. 54] In the USA, the figures for restricted mobility are prepared differently to England's but are around 10.5% of the population on a like for like basis

5. How To Further Reduce Costs…

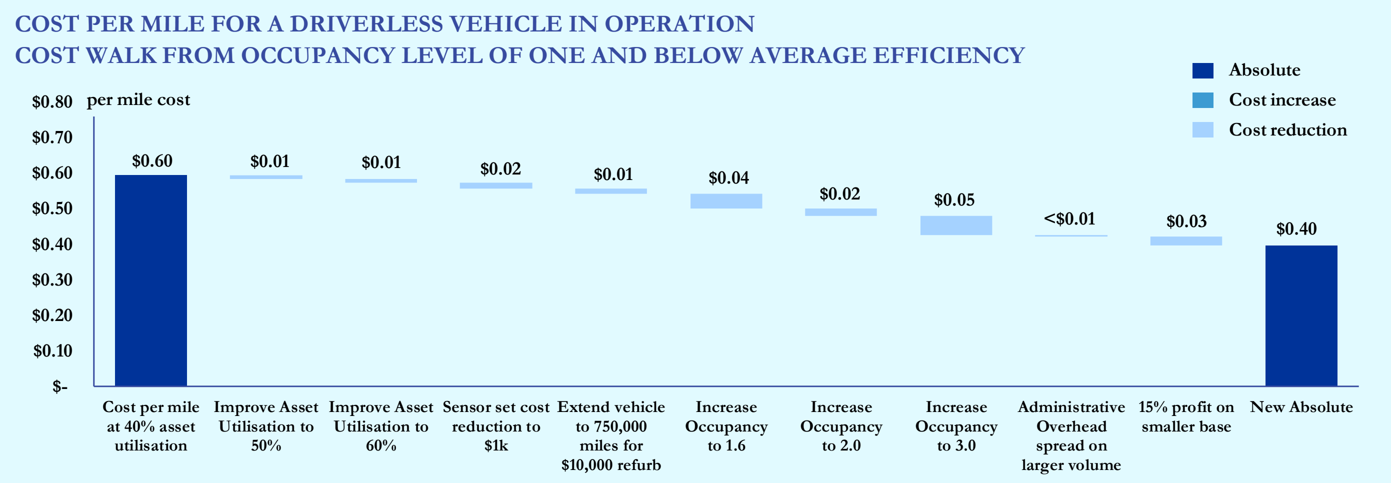
This report has demonstrated that at relatively low levels of efficiency (1.0 person occupancy, 40% utilisation and average travel speeds of about 20 mph), a service can still operate profitably with a fare level of $0.60. Improving that efficiency to the frequently observed averages (50% utilisation, 1.6 person occupancy and average travel speeds of 30 mph) mean that even with no change in human behaviour apart from accepting robo-taxis in lieu of private cars, and assuming some cost reduction from the sensor set, a profitable fare level of $0.50 can be achieved.

However, the prior section demonstrated that to fulfil 100% of travel needs, there needs to be a route to $0.40 per mile. The major options available are as follows:

- Further increases in capacity utilisation
- Reduced vehicle cost
- Increased occupancy
- Increase customer base and spread fixed costs over larger volume

This section gives an overview of the likely contribution from these different options. **Figure 55** shows a combination of these factors that could lead to a $0.40 per mile travel cost, retaining the operator's 15% profit margin.

FIGURE 55 | The Price Is Right



Source: Ad Punctum Research

Improving capacity utilisation refers here to the number of hours that the vehicle is on the road. Occupancy is a clear way to increase overall fleet utilisation but this is so big a topic as to deserve separate analysis (which follows later). Earlier, this report showed that a utilisation level of 50% does not seem an unreasonable target. Many will expect big data to play a role in optimising systems and the good news is that this can help. Studies using mobile phone data have assessed human travel patterns. A 2008 paper in Nature concluded that humans are highly predictable, noting "the recurrence and temporal periodicity inherent to human mobility". This was reinforced by a 2010 paper in Science that looked at the predictability of people's journeys through measurement of "the entropy of each individual's trajectory". Researchers found a 93% "potential predictability" noting a "remarkable lack of variability in predictability". By way of translation for actual human beings: people repeatedly make the same journeys with regular time intervals (normally 8 or 12 or 24 or 72 hours apart) and at a population level, the daily variation is small. However, the assumption of a 50% capacity utilisation already assumes that this system is being managed efficiently. Therefore, the type of areas where big data may find patterns to exploit are at the margins. For instance, it could be that rush hours takes place at slightly different times in different regions and vehicles can be redeployed across territories to best match demand.

The second opportunity for increased capacity reduction has already been mentioned: move freight trips into off-peak slots and use the same assets as passenger journeys. The analysis is theoretical as the solutions have not yet been demonstrated, but as a rule of thumb, a vehicle capable of carrying 4 or 5 passengers could be re-configured to take around 2 metric tonnes of freight (the freight top hat would have a higher roof). If all freight was moved in these type of vehicles -- an over-optimistic assumption given the existence of bulk freight and wide loads -- then the road mileage would

NOTE: The 2008 paper is by Gonzalez M et al titled "Understanding human mobility patterns".
The 2010 paper is by Song C et al titled "Limits of predictability in human mobility". The full references are in the Acknowledgements and sources of data section.

be somewhere between 30% to 50% of the passenger mileage. If the freight were successfully switched to lower demand times, which does not mean only late at night as there is some surplus capacity during the day, then capacity utilisation could be pushed north of 60% and maybe even towards 75%.

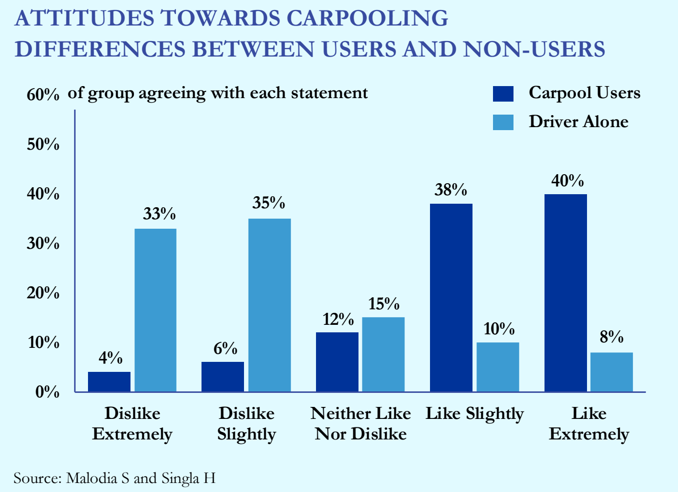
The next group of opportunities concern costs. The cost of the sensor set itself should come down as the technology matures. At a cost of near $10,000 in the early 2020s (the $5,000 to $5,500 from Delphi plus manufacturer mark-ups), the cost may have reduced to be closer to $1,000 by the late 2030s through the maturity of the technology and lower profits from commoditised product.

With a fleet utilisation of 50%, even at a replacement mileage of 500,000, the vehicle lifetime will only be around 3 years. This seems young to dispose of a vehicle. Manufacturers and owners may therefore find an alternate option: designing vehicles for an expensive mid-life update (like a cabin refurbishment for a commercial airliner) that will keep it in productive service for longer without decreasing revenues. Customers will care that the seat fabric and cabin is in good condition but will judge the air conditioning on a more functional basis -- either it works or it doesn't. Taxis in London and New York reach 500,000 miles without any type of refurbishment program.

The final option for reducing vehicle cost is commoditised, mass manufacturing. Could the autonomous vehicle become a commodity in of itself as with smartphones where components are standardised and manufacturing can take place in lower cost locations and then be shipped around the World? In time, almost certainly yes. Buses are already heading this way with Chinese manufacturers winning market share in Western markets (and having greater success than for cars). There will be challenges from Western politicians trying to defend their share of value-added and this will slow the rate of migration. Even without the difficulty of integrating advanced autonomous technology, today's Chinese vehicles lag Western quality standards. However, they are catching up. Fast.

Increased vehicle occupancy is being relied on to deliver considerable cost reductions. The good news is that the cost reductions from increasing the number of people sharing the vehicle are real and the most substantial single way of improving the cost structure. There are challenges however. People simply don't like travelling together very much. The phenomenon of sharing with strangers has been studied extensively since carpooling schemes became common in the 1970s (1977s Ride Sharing: Psychological Factors was something of a watershed). In carpooling schemes, participants arrange to share a car, sometimes as either driver or passenger only, sometimes sharing driving and normally on routine journeys such as commuting to work. **Figure 56** shows the findings of a 2016 paper into carpooling attitudes in India.

FIGURE 56 | Different Strokes



Source: Malodia S and Singla H

The consumer feedback in Figure 56 shows that most drivers dislike the idea of carpooling but that most people taking part in carpools quite like it. This demonstrates the instinctive negative reaction towards the concept of sharing a small vehicle (there is plenty of other research available supporting the same conclusion) and that the more positive view of carpooling in the main comes through experience -- something that people can deliberately opt out of.

This is not to say that people will not share vehicles where the right incentives exist. In a 2006 paper called "Slugging in Houston" the authors documented casual carpools in Houston (USA). Drivers and passengers would gather at impromptu meeting spots to arrange journeys into the city. The advantage for the passengers (the "slugs") was the free ride. The benefit for the drivers (the "body snatchers") was being able to use lanes for high occupancy vehicles only and beat traffic.

If occupancy rates could be increased to 3 people per vehicle -- almost double today's average of 1.6 -- then a cost of $0.40 per mile would be in sight. Creating a system that could manage an occupancy of 3 people per vehicle is certainly theoretically possible. A 2017 paper looking at trip optimisation concluded that if New York taxi journey requests were amalgamated -- an UberPool type service -- then vehicles with a capacity of 4 (a normal car) would be able to fulfil 98% of

NOTE: The 2016 paper is by Malodia S and Singla H and titled "A study of carpooling behaviour using a stated preference web survey in selected cities of India"
The 2017 paper is by Alonso-Mora et al and titled "On-demand high-capacity ride-sharing via dynamic trip-vehicle assignment"

journeys with mean waiting times and trip delays of about 5 minutes. Although this study didn't quite achieve occupancy of 3, it shows that increased trip times would still be measured in single-digit minutes.

This level of on-demand service would be insufficient for today's private car owners who are used to a zero-minute wait time and travelling without strangers in the vehicle -- but they can pay $0.50 - $0.60 per mile for that privilege. The 2016 paper on carpooling in India found that although cost is the strongest factor in choosing to carpool or travel separately, qualitative variables still matter. There is the "strongest preference for extra travel time to be less than 5 minutes" but these are private car users, not public transport customers. Running with higher occupancies would allow public transport users to access the service at a price in line with today's fares and a substantially better service. Although waiting times will be greater than the single user service, public transport users in the USA currently suffer travel times of half an hour more than private car users. Even a 10-minute wait time would be a 2/3 improvement.

Why say that public transport delivered through autonomous vehicles with a high number of occupants would be a "substantially better service"? Autonomous vehicles operating dynamically can provide a door-to-door service. No more waiting at windy bus stops or walking 200 metres through puddles to get from the nearest light rail station to the office.

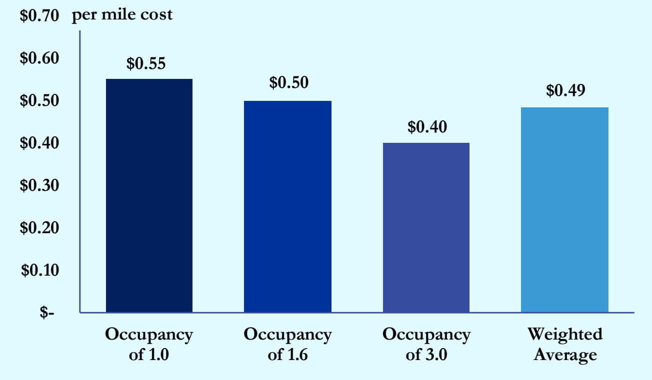
It will be interesting to see how cabin designers respond to this challenge. Do they simply provide a cabin much like today's and have higher-paying occupants ride alone or can they create some way to provide private spaces within a shared cabin that will allow the operator to charge for solitude as they provide sharing?

The final cost opportunity comes from the old chestnut of winning extra business and spreading more revenue over fixed costs. We aren't ones to doubt the success of this strategy -- plenty of failed business plans do that hard work for us. Instead we would point to the marginal benefits of this as a pillar of cost reduction strategy. Operating costs for on-demand services will only be single-digit cents per mile in an efficient system. As Figure 55 shows, improvements will not make much headway into the overall cost. Operators should look at other strategies for big wins (in our view).

How might a system balance the need to provide a service at $0.40 per mile to capture public transport users, yet also cater to those with deeper pockets who are put off by the idea of sharing with strangers? The solution lies in a different pricing structure depending on whether the service is "Solitude" (like today's private car) or "Shared" (like public transport but a bit less crowded). **Figure 57** shows how operators profitable fare level varies with different average occupancies. **Figure 58** shows the travel costs for users choosing between a solitude (at $0.55 per mile) or shared (at $0.40 per mile) service.

FIGURE 57 | Different Use Cases

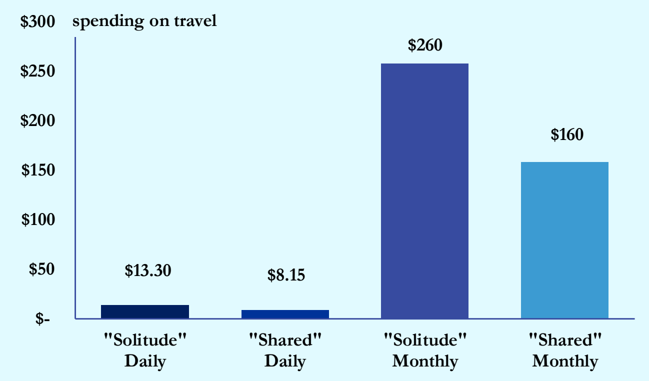
PROFITABLE OPERATING COSTS
UNDER DIFFERENT OCCUPANCY ASSUMPTIONS



Source: Ad Punctum Research

FIGURE 58 | Affordable For All

COMMUTING COSTS (ROUND TRIP)
FOR DIFFERENT USER GROUPS



Source: Ad Punctum Research, APTA

The weighted average in Figure 57 reflects that if current transport choices held, about 15% would choose the shared option. Of course, an operator could make customers take pot luck on whether the trip was shared and charge a single overall tariff but with the larger market share in people who currently use their private cars and receive solitude, this approach might provide a service that the majority are not asking for. It may be that in time, as people experiment with using the shared approach every so often, the findings of Figure 56 prevail and the market share of the lower cost "shared" service grows. In the cost analysis above, operators can afford to be agnostic about consumer choice -- they make a return either way and simply adjust their fleet sizes in response. Providing the trend is predictable (research suggests it is -- very much so), they will be untroubled by longer-term adoption of sharing.

Figure 58 fare levels are based on the average commuting distances in the USA. To some car users, a rate of almost $15 per day might seem quite expensive, but this is the all-in cost -- it is not directly comparable to the cost of fuel alone. Looking at the monthly figure might provoke a more measured response. $260 per month is consistent with the monthly payments on a smallish non-premium car. The $160 figure is in line with travel passes, this is no surprise since our target cost of $0.40 is derived from such products.

Some might question the maths used in Figure 57. If the occupancy goes from 1 to 2, shouldn't the fare be halved? In theory, yes, if everyone all takes the same journey then the costs can be reduced like this. However, even in a theoretical environment, researchers don't seem to be able to create these conditions. They find that systems with higher occupancy and shared trips are more efficient but that this comes at a cost of additional waiting and travel time. This is because the vehicle is covering additional mileage to link up the disparate customers. Whilst customers may accept this travel time, they will not regard it as valuable. This report's assessment of the higher occupancy systems treats this non-valuable time as a form of additional inefficiency. Whilst the overall effect is clearly positive financially therefore, it is not linear. Who is to say what assumption is right or wrong? An answer will eventually emerge. It seems fair to say that the analytical approach in this report is conservative.

Is there a downside to all in this future where travel s on-demand and driverless? Perhaps. The focus of negative comments is on two issues; unbearable traffic and environmental concerns.

In an apocalyptic scenario, traffic grows exponentially and cities become perma-gridlocked. This type of futuring attracts plenty of column inches but doesn't bear much intellectual scrutiny, for the following reasons:

- Travel has always been growing, irrespective of the mode, and through all that time people have forecast in a Malthusian fashion that transport capacity was about to be breached. Somehow a way keeps being found.
- Without any purpose-built autonomous robo-taxis on the road today, their footprint is guesswork. In the initial incarnations, integrating autonomous equipment in a conventional vehicle may be sufficient but as the business matures, the search for competitive pricing will drive the generation of fit for purpose vehicles. These may well be smaller than cars we see on the roads today. If the service knows that you are travelling in the city then it sends you a one person low speed pod. Only if you are making an intercity journey would you travel in something that looks like one of today's cars.
- The entire concept of parking as we know it will change. Autonomous vehicles will need some parking, as our capacity projections have demonstrated, but they will be on the road for far longer each day than private cars and there will be less of them in total. Extra space will be created through the elimination of road-side parking and the traffic congestion caused by people looking for parking spaces in busy areas will disappear.
- The ongoing theme of this report is that travel is governed by price above all considerations and that the operator profits (and thus the fares that they can offer) are dependent on capacity utilisation. If traffic becomes unmanageable, capacity will drop, fares will increase and fewer people will travel.

The environmental impact of the private car, and transport in general, has long been an issue that attracts attention, lobbying and even government intervention.

We believe that within a short space of time, all autonomous vehicles operated for profit in cities will become fully-electric. There will be pressure from local governments to offer some benefit in return for operating licences. The more relaxed customer experience that comes from a quieter cabin will also be a factor. At present, arguments as to why electrification is not necessarily the de facto power unit come in three flavours: (1) the car will need to recharge all the time, (2) the car will be too expensive, (3) the load of autonomous electrics on the vehicle is too great. Taking the recharging argument first, this is normally made without reference to human patterns of travel. As we have demonstrated in this report, fleets providing mass transit can only target 50% utilisation with any seriousness. This leaves plenty of time for charging, especially given that 350 kWh (+) chargers can provide over 100 miles of range in a matter of minutes. The argument that the vehicle will be too expensive misses the wider dynamic, the vehicle will be a commercial asset, not a private car. If the only way that operators can get a licence is to buy electric, they will do so. It also ignores progress on battery costs. By the mid-2020s (setting forecasts of cost parity to one side), the cost differential will be substantially lower than today. On the final issue of power drain from electronics, there will be advances in lower-power systems. Ultimately this becomes a variant of the first argument -- the vehicle will drain the battery and need re-charging but there will be time for that.

The vehicle fleet will be far smaller than today and the ongoing production will be lower too. Although this doesn't change the variable per-mile environmental impact of travel, it makes a considerable difference to the whole-life impact. Cutting vehicle production by over two thirds not only saves emissions and energy consumption in the final assembly plants. Cumulatively, that reduced production takes millions of tonnes of steel and plastics production with it.

Any type of car is going to struggle to compete on environmental terms with an electric train (negating the environmental cost of constructing the line and stations), but it will substantially reduce input energy for construction of vehicles, create more open space and improve tailpipe emissions (although it could be argued electrification is an inevitability whichever version of the future of car ownership one subscribes too). Overall then, the argument might not overwhelm ardent greens who dream of a world where people only ever travel by walking or cycling (much to the detriment of range) but it will be a considerable improvement on the environmental impact of today's transport set up. And for those who complain that it will increase travel volumes we can only say; that is inevitable anyway (remember that the UK government is forecasting a 60% growth between 2010 and 2040 in some scenarios without even considering the impact of autonomous vehicles). It is important to recognise that the reduction in vehicle parking could create a substantial increase in open spaces (of course, people might simply build on it).

Overall, we prefer a sunnier vision of the future. Travel will become cheaper and less stressful. With a cost of $0.40 in sight, public transport users can dare to dream of chauffeured door-to-door transport that today is only enjoyed by the richest members of society. The advent of autonomous vehicles frees up space in city centres and is a major catalyst of pure-electric vehicle adoption, improving air quality. Good news for everyone apart from car factories and steelworks. Tyre makers will still have wide smiles on their cheeks. The next challenge for customers will be finding what to do with all the time they suddenly have on their hands. More cat videos perhaps?

In summary, from looking at the cost structure of an on-demand business, it is possible to conclude the following:

- **Travel at $0.40 per mile is within reach.** It might not even require special vehicles. Although research work continues into on-demand vehicles with capacities of 10 people and above, this may remain in the domain of pure academia. A system carrying an average of three people at a time could still be profitable and use the same vehicles for solitary customers paying a higher price.
- **A price structure similar to UberX versus UberPool is likely to persist.** Creating a single fare level ignores some of the fundamental dynamics of human choice. In general, people don't like to share if they can afford it. Therefore, it is more likely that richer people will choose to pay more to ride alone or with close family and friends.
- **Governments are going to face some tough decisions on public transport eventually.** If on-demand services can match the $0.40 per mile price point as we forecast then customers will adopt on-demand due to its lower overall travel time, door-to-door service and additional convenience ("remember the olden days when we actually used to stand in the bus?"). This will be a mixed blessing for governments. On the one hand, they can remove the substantial subsidies currently paid to public transport operators. On the other, vested interests (those losing their jobs -- from station masters to route-planning bureaucrats) and political idealists (who hate the idea of the private sector running transport) will lobby not to abandon public provision of services. They will have more success in some countries and cities than others.

6. The Customer Journey: Some Scenarios

Having covered so much ground in this report, it is easy to lose track of the fundamental customer experience being described -- especially since this is likely to evolve over time. This section is intended to give an idea of how services might evolve from the customer's perspective.

Early Stage -- Solitude

Jeremy fishes out his smartphone and opens the ride-sharing app to call a cab. Licenced taxis were always too expensive for him to use but the advent of ride-sharing means he can afford the occasional trip. He has always been used to seeing two options: Solo travel and group travel, but now a third is displayed. Making a joke of the fact that the driver is a computer (some call it a robot but there is no physical driver), the service is called HAL. It is priced at the same level as the shared service but Jeremy is guaranteed to be the only passenger.

This is now the option he always chooses. When asked why, his reply is simple: it's the cheapest, I get to travel in peace and I trust the technology because if the robo-taxi can't complete the route properly they send me a taxi with a human driver, which is what I was used to before. In his experience, this happens about 20% of the time.

There is also a competitor out there, it uses other people's cars to make the journeys in autonomous mode. Although at first Jeremy was attracted to this by the idea of paying other people rather than a corporation, now he doesn't bother checking. The peer-to-peer service seems to have very few cars on it, it is expensive, the cars are inconsistent (sometimes big and sometimes small) and they don't seem as clean as the cars run by the operator he uses.

Increasing Maturity -- Solitude

Anxious to make her appointment, Susie hurries out the house to the waiting car and the doors open as she approaches. She no longer owns a car, instead paying a monthly subscription for an always-there service. She doesn't have a car of her own but through monitoring her calendar, being linked to the smart home devices and the GPS in her phone, it somehow nearly always manages to have a car just outside her door without her having to even think about it.

On the odd occasion that the system hasn't been proactive enough, two taps on her phone or a simple instruction to the smart home system summons one. It always arrives within two minutes. Susie laughs, "that's less time than it used to take to get the car out of the garage".

Susie made the switch because the subscription service guaranteed it would beat her prior travelling costs -- they even gave her a trade-in value for her car in exchange for her choosing a contract. She likes that the car is always clean and she gets to relax rather than having to drive.

Actually, she remembers, sometimes she does have to do a little bit of driving -- when there is something the autonomous car would struggle with. She likes that this is never a surprise. The car analyses the route and tells her if any of it will be a trouble. It then gives her two options -- she can drive the whole route (satellite navigation directions appear on a cool heads-up display) or the car will drive until it needs her help, then pull over and she takes control. This happens once every couple of months. When Susie first signed up to the service it was every few weeks but the rate is noticeably lower now.

Something that still wows her is that she can leave stuff in the car if she wants. The service provider has a network of automated sites across the city. Robots remove a box containing her valuables and then put into the next car just before it meets her to take another trip. Not all operators offer this and it is a big part of Susie's loyalty to this service.

One of the coolest things is that the subscription covers this operator and their partners all over the world (wherever there are autonomous vehicle services, which in practice is most rich countries). Even in places where they don't have autonomous vehicles she can still use vehicles with a human driver and the service charges her a top-up.

Fully Mature -- Solitude

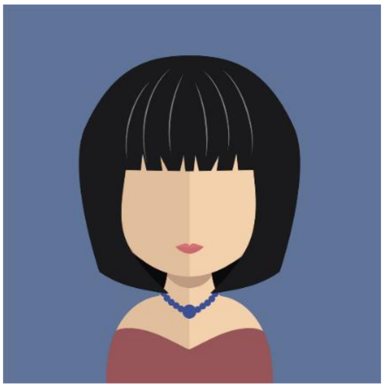
Alphonso runs up to the waiting car, excited to get to his friend's house. As a boisterous teenager, he loves going to meet up with his friends (he always tells his parents it is to study -- they let him think he has got the better of them).

His travel is covered as a part of his parents' travel subscription plan. It guarantees that he is in the car alone (unless he is travelling with friends -- it is linked to his Facebook profile to know who his friends are). It could also tell them the status of his trips, but their linked smartphones do that anyway.

During the journey, Alphonso thinks about how strange it seems that people used to be nearly 20 before they could enjoy freedom like this (there was something called a "bus"). Even then, they had to ask nicely to borrow the car. He goes wherever he wants (on trips farther afield his parents confirm using their smartphones that they are happy for him to go on such a long journey).

When his friend Mike was in town for a few hours waiting for a connecting flight, Alphonso was able to pick him up in a car and they did a tour of the city, during which Alphonso pointed out all his favourite sights. Alphonso's parents could never have imagined being able to do anything like that.

Fully Mature -- Sharing



After what seemed like a night shift that went on forever, Gwen can't wait to get into the car that will take her home. As she exits the hospital she confirms that she is heading home and the phone directs her to a spot on the pavement, within two minutes the car arrives and she gets in, saying a polite hello to the two other passengers. Gwen recognises one of them as the guy who was in the same car as her last week. He works at that cool bakery down the street (is his name Tony or Pete?) and gives her a big smile as she gets in.

Gwen relaxes into her chair. A message appears on her phone asking her to confirm the seat and temperature settings to use -- should they be the same as last time? Air temperature yes, massage mode on the seat this time please. The car can connect to her phone and wireless earphones on a larger screen that comes down from the ceiling but tonight she wants to be in peace.

After such a hard shift, she nods off and only wakes as her seat headrest and smartphone begin to buzz gently and a subtle ringing tone plays. This means that she is almost home. As she gets out she notices that she is the only person left in the car. She has shivers as she remembers that she used to catch the bus home from work. It wasn't just that she had to wait in the cold for it to arrive but there was a long walk home. Not only that, every so often Gwen used to fall asleep like she did tonight. If she was unlucky, she wouldn't wake up until she had missed her stop.

This service costs less than the bus, her travel time is half what it used to be and the seats are fantastic. At first Gwen wasn't totally sure about the service so she used to pay trip-by-trip. It was about the same cost as the bus. Now that she is confident, she has signed up to a subscription service. The monthly cost is the same as her travel pass was but this gives her more miles for social trips. Overall, she spends less than she used to. Although the pricing is based around the shared service, her subscription includes some "premium" miles where she can be sure of privacy -- great for when work has been particularly stressful or for going out. She can take two or three trips a week in solitude, depending on the distance.

Gwen has noticed that nowadays more people seem to be using the shared service. The cars themselves haven't become any busier -- there are only four seats after all -- but Gwen notices that people in more expensive suits seem to be sharing with her than before.

In Closing: A Summary Of This Report

This report was written to robustly assess, from first principles, the arguments being made around the timing and impact of driverless on-demand mobility. Existing analysis in the main either jumps to bullish conclusions without clear linkage to reality or unabashedly supports the status quo of car ownership, without regard to the emergence of disruptive technology. We believe that the status quo is not car ownership; it is humans travelling in relative solitude for an hour or so per day. The transport mode is a secondary decision made by people based on the options before them at that time.

A switch in transport mode will be determined primarily by the price, with consumer attitude and regulatory factors being important secondary considerations (as when people chose cars above horses). Once driverless technology matures and regulators devise suitable operating rules, an on-demand virtual chauffeur will be cheaper than driving your own car.

This report demonstrates that mass-use of on-demand mobility will soon be a reality in the rich world -- with multiple scenarios for the rate of growth. Few will resist the temptation to switch once a service is proven to offer cheap, round-the-clock travel -- even people who today swear they will be petrol-heads forever. The key findings are as follows:

Current data shows that current average travel spending is about $0.70 per mile. Many countries publish data on miles travelled, and the way in which they do it. Mobility services are competing for a share of this spending.

Car ownership suffers as on-demand goes mainstream. Whilst overall travel will increase and people may switch from public transport, most on-demand share growth is out of private cars -- they provide over 80% of road travel today.

The potential revenue of a wholesale switch to on-demand is huge -- $6 trillion per year. Each year, the combined populations of the EU, USA and China travel more than 8 trillion miles by road, and this will increase with economic growth. Even without changing travel patterns, on-demand can compete with car ownership for a share of these trips.

Establishing a viable on-demand model faces a big problem -- capacity utilisation. This report shows that the pattern of "rush hours" holds across different regions and countries. Without sufficient capacity, people won't give up their cars. If they don't do that, on-demand struggles for market share. Utilisation assumptions above 50% are optimistic.

Driverless cars will dramatically reduce car production -- by between 60% - 75%. At present, the car industry seems to be assuming demand stays the same whatever the tool being used (private car or robo-taxi). Unfortunately, although miles travelled will increase, driverless cars that last longer than they do today (500,000 miles is a reasonable starting point) and are far better utilised than private vehicles -- at least 40% versus 5% -- mean demand shrinks considerably.

Autonomous vehicles will be capable of most journeys by the early 2020s. The classic driverless test of a narrow urban road featuring a stream of life-or-death decisions is a rarity. Around 70% of travel in rich countries is on major arterial roads and highways -- the technology is nearly capable of this now and will be ready around 2020. Driverless cars don't need to be capable on 100% of routes to capture share, the network will grow road-by-road, just like cable TV.

Widespread autonomy will take a significant share of travel by 2030 -- at least 40%. Adoption rate depends on three things: price, technology and regulation. Market modelling suggests mass switchover will have two stages: the first comes when on-demand is cheaper than car ownership ($0.70 per mile); the second is at cost parity with public transport ($0.40 per mile). Regulation and technology progress influence growth rates -- share in 2030 could be 40% or 80% depending on how favourable they are. Regulatory consent will come at a cost -- such as licences being restricted to electric vehicles.

On-demand could increase miles travelled by around 25% compared to cars today. This would mean replacing public transport and increasing the travel of users with restricted mobility. Until on-demand can offer fares of about $0.40 per mile, most public transport users won't switch -- unless an alternative way of using existing subsidies can be found.

What does this mean? The adoption of on-demand mobility is going to depend primarily on cost. Although adoption scenarios vary in timing by a decade due to variation in regulatory and consumer preference, there is a route to $0.40 per mile across regions. Mass adoption will considerably reduce vehicle sales, so for carmakers the exact timing is academic -- they should begin planning for massive capacity reduction. An industrial purchasing base may support fewer brands too (aircraft, oil service suppliers, mobile phone infrastructure builders point in this direction). Suppliers will worry too. For everyone else? Chauffeurs for all (in time)! Catch up on sleep, start a food blog for pets or maybe just take in the scenery.

Acknowledgements & Sources Of Data

This report contains extensive reference to third party materials. This section is not an exhaustive list of all the materials read in preparation of this report but it covers those that have been directly referenced. It may not include sources which are judged to be fully explained in the text or footnotes (including Figures with the report body).

American Public Transportation Association (APTA)

This body has a wide range of members, covering numerous companies and government bodies involved with public transport in the USA. It produces statistics and reports, made available on its website at www.apta.com. Where "APTA" is cited as a source, it refers to the following publication:

- Shared Mobility And The Transformation Of Public Transit, Washington, DC, March 2016
- 2016 "Travel Like A Local" Summer Travel Survey, Washington, DC, May 2016
- Who Rides Public Transportation, Washington, DC, January 2017
- 2016 Public Transportation Fact Book, Washington, DC, February 2017

BAST

BAST is the German acronym for the Federal Highway Institute, an arm of the German government. Where "BAST" is cited as a source, it refers to information published on BASTs website, www.bast.de. The primary reference document used for this report is the traffic data report "Verkehrsentwicklung auf Bundesfernstraßen 2014".

European Commission

The European Commission publishes through the EU Bookshop website and materials may be obtained, in electronic format, free of charge from https://bookshop.europa.eu. Where "European Commission" is cited as a source, it refers to the following publications:

- Driving And Parking Patterns Of European Car Drivers: A Mobility Survey -- Published in 2012
- EU Transport In Figures: Statistical Pocketbook -- 2016 Edition
- Occupancy Rates Of Passenger Vehicles -- European Environment Agency 2010

New York City

Various data can be found through the NYC OpenData portal, https://opendata.cityofnewyork.us/ including traffic data. The New York Taxi and Limousine Commission (TLC) publishes a Taxicab Fact Book in selected years.

Transport For Greater Manchester (TfGM)

Transport for Greater Manchester is the authority governing much of the travel in and around Manchester. It publishes various reports on its website www.gmtu.gov.uk including road traffic and public transport data.

Transport For London (TfL)

Transport for London is the authority governing much of the travel in London and is controlled by the Mayor of London. It publishes various reports on its website. Where "Transport for London" or "TfL" is cited as a source, it refers to the following publications:

- Annual Report and Statement of Accounts -- various years, the latest being 2015/16
- London Travel Demand Survey
- Other data including taxi meter regulations and funding summaries

Transport Scotland

Transport Scotland publishes various data about travel in Scotland. The primary reference document used for this report is "Scottish Transport Statistics 2016 Edition".

UK Department for Transport (DfT)

The UK Department for Transport publishes a wealth of information about travel in the UK. Where "Department for Transport" or "DfT" is cited as a source, it refers to the following:

- Data on traffic counts, vehicle population, accidents and other road data available on the data.gov.uk website
- Road Traffic Forecasts 2015 -- Published in March 2015
- Transport Statistics Great Britain 2016 -- Published in December 2016

US Department of Transportation

Cited as "Department for Transportation", "US NHTS", "US DfT" or "Federal Highway Administration" in this report. The primary reference document used is the "2009 National Household Travel Survey" -- This survey is conducted every few years and was last published for 2009 data (published in 2011). 2016 results are currently being collated.

Academic Papers

This list is only the material directly referenced in this report

- **Alonso-Mora J, Samaranayake S, Wallar A, Frazzoli E, Rus D** (2017) "On-demand high-capacity ride-sharing via dynamic trip-vehicle assignment" Proceedings of the National Academy of the United States of America Vol. 114
- **Burns M, Winn J** (2006) "Slugging in Houston - Casual Carpool Passenger Characteristics" Journal of Public Transportation Vol. 9
- **Dueker K, Bair B, Levin I** (1977) "Ride Sharing: Psychological Factors" Transportation Engineering Journal of the American Society of Civil Engineers.
- **Gonzalez M, Hidalgo C, Barabási A-L** (2008) "Understanding individual human mobility patterns" Nature p. 779-782
- **Malodia S, Singla H** (2016) "A study of carpooling behaviour using a stated preference web survey in selected cities of India" Transportation Planning and Technology Vol. 39
- **Martin E, Shaheen S** (2016) "The impacts of Car2Go on vehicle ownership, modal shift, vehicle miles travelled, and greenhouse gas emissions: an analysis of five north America cities" UC Berkeley working paper
- **Rose J, Hensher D** (2014) "Demand for taxi services: new elasticity evidence" Transportation Vol. 41
- **Song C, Qu Z, Blumm N, Barabási A-L** (2010) "Limits of predictability in human mobility" Science p. 1018-1021
- **Wang T, Chen C** (2014) "Impact of fuel price on vehicle miles travelled (VMT): do the poor respond in the same way as the rich?" Transportation Vol. 41

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