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Transport 2020: Addressing Future Mobility Needs

A Report on the Discussion Held by the TRL Fellows in December 2016

TRL THE FUTURE OF TRANSPORT

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1. Introduction

The following whitepaper is based on a discussion on transport and mobility that took place between Fellows of the Transport Research Laboratory (TRL) in December 2016, during a dinner hosted by TRL and led by Prof Nick Reed, TRL Academy Director.

The Fellows are members of academic institutions and transport-related organisations who are highly respected researchers and practitioners and who are interested in the development of future mobility to meet the changing requirements of today's digital society.

By bringing together this diverse community of experts to discuss key transport and mobility questions, TRL hopes to gain a range of perspectives that merit consideration as we prepare for changes that will affect us all.

During the meeting, the Fellows discussed what transport and mobility issues need to be addressed by 2020, what capabilities will be required to address these questions, and how the Fellows can support TRL and the wider research community in achieving these objectives.

The Fellows also debated the social, health and safety, environmental, ethical and economic impacts of current and future modes of transport.

This whitepaper summarises the Fellows' views on the technological, infrastructural and societal changes that will be required to support the migration to sustainable, zero emission modes of transportation that support productivity and contribute to the economy.

The whitepaper also poses the question as to how policy makers, manufacturers, academia and industry can work together most effectively to meet transportation and mobility requirements of the future.

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2. The Future of Transport

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In the last forty years there has been a growing consensus among academics, government bodies, medical professionals and the automotive industry that future modes of transport must be made more sustainable by reducing reliance on fossil fuels in order to reduce the detrimental impact that petrol and diesel combustion has on the environment, air quality, public health and the economy.

More recently, there has been the realisation that roads will need to work smarter to withstand the growing population and number of vehicles on the road.

The increase in population density, particularly in urban areas, means that new ways to reduce congestion and air pollution are required urgently, in addition to the accepted need to continue the reduction on road traffic accidents and injuries, the largest number of which are caused by human error. New and emerging technologies potentially hold the key to these issues.

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3. The Drive for Ultra-Low Emission Technologies

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According to the World Health Organisation, an estimated 40,000 to 50,000 people[1] in the UK die prematurely each year from diseases caused by air pollutants, such as fine particulate matter, NOx and ozone.

An EU review[2] found that six million working days are lost from air pollution-related illnesses each year, costing the economy €28 billion.

Britain has been in breach of European Union nitrogen dioxide (NO_2) limits since 2010, receiving air pollution fines as a result, while London went beyond its annual pollution limit for 2017 in the first five days of January alone.

Environmental scientists, governments and manufacturers have been working together for decades to address this situation by developing alternative power sources for consumer and commercial vehicles.

To manage emissions they must first be measured. Tests have shown that real driving conditions emit more NOx than the current laboratory-based type approval emissions test, leading to the introduction of Real Driving Emissions tests in 2017. Portable emissions measurement systems (PEMS) were developed to provide the government, manufacturers, fleet operators and drivers with real world data on particulates and gases emitted during real driving conditions.

In 2015 the former Mayor of London, Boris Johnson, announced that central London would become an Ultra-Low Emission Zone (ULEZ) on 7th September 2020: giving vehicle owners five years' warning to reduce emissions, change their vehicle, or pay a daily charge to drive within the zone.

TfL has been lobbying the Office for Low Emission Vehicles for further funding to support the adoption of low and zero emission vehicles. The current London Mayor, Sadiq Khan, wants to introduce the ULEZ sooner – central London ULEZ in April 2019 – with further proposals to expand this over a wider area.

Some cities are going further: Paris, Mexico City, Athens and Madrid have all committed to ban all diesel powered cars and trucks by 2025. Action by key UK cities could make the purchase of new diesel cars unattractive.

The Fellows discussed what else needs to be done to encourage more drivers to adopt 'cleaner' vehicles and the implications for existing road infrastructure if more people adopt electrically-powered vehicles.

Regulators are increasingly looking to penalise manufacturers that fail to comply with emission reduction targets. The automotive industry is under pressure to develop low or zero emission vehicles, hence their increasing focus on electrically-powered and autonomous vehicles, which can be driven at optimum efficiency for the conditions.

The Fellows recognised that the reduction of diesel use for commercial vehicles will present a challenge for many industries and acknowledged the work that Transport for London (TfL) and other local authorities have done to reduce the impact of diesel vehicles on air quality and public health. They also acknowledged the fact that newer Euro 6 diesel trucks emit less CO_2 and particulates per mile than many passenger diesel vehicles that are currently on the roads.

They asked whether government legislation and public opinion might make it uneconomical for manufacturers to continue to produce small passenger diesel vehicles. However, this would not address the issue of pollution from existing diesel cars and vans. Others added that more must be done to monitor local effects of air pollution at sensitive locations such as schools.

It was suggested that the government could provide incentives for owners to remove existing diesel engines from use through a scrappage scheme. The Department for Transport and Defra are working on a scheme to offer discounts on low-emission vehicles[3], or cashback to drivers who trade in old, polluting vehicles.

The EQUA Air Quality Index uses PEMS data and is being modelled as a Euro NCAP rating for emissions that could be used to guide vehicle purchasing decisions.

[1] https://www.independent.co.uk/environment/dozens-of-british-cities-are-breaching-air-pollution-limits-in-public-health-crisis-a7025401.html

[2] https://www.theguardian.com/environment/2017/feb/06/european-commission-escalates-action-uk-breaching-air-pollution-limits

[3] http://www.telegraph.co.uk/news/2017/02/02/officials-drawing-plans-diesel-scrappage-scheme-cut-emissions/

> **"Britain has been in breach of European Union nitrogen dioxide (NO_2) limits since 2010, receiving air pollution fines as a result, while London went beyond its annual pollution limit for 2017 in the first five days of January alone."**

3.1 Changing User Behaviour

Range anxiety is one of the key deterrents cited by people who would otherwise consider moving from a fossil fuelled vehicle to an electrically-powered vehicle.

The Fellows discussed how users might be encouraged to adopt multi-modal transport: combining the use of ultra-low emission vehicles (ULEVs) with walking, cycling, and journeys made on public transport.

It was suggested that, while addressing air quality issues, if autonomous vehicles became too accessible, low cost and convenient within urban environments, this could have a detrimental effect on public health by deterring people from cycling or walking.

3.2 Infrastructure to Support ULEVs

New ULEV models[4] are being developed globally by all manufacturers, including: Tesla, Ford, Nissan, BMW, Mercedes, VW, Audi, Renault, Peugeot, Citroen, Kia, Toyota, Mitsubishi, Hyundai and Google. While electric vehicles have had a limited impact on UK roads so far, market research firm IHS predicts[5] that sales of battery-powered electric vehicles and hybrids will increase to 11.5 billion units by 2022 and represent 11% of the global automotive market.

The Fellows pointed out that more widespread adoption of ULEVs needs to be matched by road infrastructure as drivers will need to be assured that they can reach their destination without running out of power and without having to queue to access a limited number of charging points.

Car batteries may come to be viewed more as consumables, or loaned rather than owned assets. While this would address range anxiety by allowing drivers to quickly swap out fully charged batteries at multiple charging points along the road network, this would present major technical challenges. A more probable solution would be the development of more efficient car batteries that charge more quickly and the use of induction charging.

The Fellows suggested that in inner city areas, served by electrically-powered buses, public transport operators could install induction charging plates at depots, to allow buses to be charged overnight. They also suggested that roadways could be adapted to include charging lanes, allowing drivers whose batteries are running low to move into these lanes. This change to the roadway infrastructure would keep traffic flowing and reduce congestion at service stations and other public charging points.

Motorway service stations might need to be adapted to accommodate, entertain and offer additional services to drivers who have to wait a little longer to top up their vehicle batteries. Other experts have suggested that drivers might collect pre-charged batteries at service stations and swap out spent ones before continuing with their journeys. However, issues around standardisation of the technology and constraints on vehicle design introduced by this approach has led to alternative strategies being pursued.

The Fellows also pointed out that, even with a mix of vehicle propulsion systems, energy could prove to be an important limiting factor in the adoption of electric-powered vehicles. They debated the potential impact on the national grid during peak travel periods. Energy efficiency will still be important for ULEVs, not only for maximising range but enabling the power networks to meet demand.

[4] http://www.nextgreencar.com/emissions/low-emission-cars/

[5] http://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/urban-mobility-at-a-tipping-point

4. Connected and Autonomous Vehicles

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A growing number of connected vehicles can be found on UK roads today, providing drivers with more information, resources and entertainment. The Fellows discussed the role of reliable networks for supporting connected and autonomous vehicles of the future.

Vehicle connectivity currently depends on reliable 3G and 4G networks to support in-car interactions. 5G will potentially support automated vehicle technologies by providing low-latency networks for real-time communication between vehicles and their environment and over the air software updates for vehicle control systems.

Connectivity is essential for effective management of automated vehicles, however, the Fellows pointed out that no vehicle should depend on connectivity for its safe operation. They mooted that, as in the aviation sector, highly or fully automated vehicles must always have a safe fall-back level of operation, so that the vehicle can safely protect its occupants in the absence of any connectivity.

The Fellows recognised that automated vehicles offer a potential safety benefit by reducing road traffic accidents caused by human error, which claim up to 1.25 million lives each year around the world. While automation will not completely remove human error from transport operations, it offers the potential to tackle key risk factors on our roads including driver fatigue, impairment and inattention. However, they also warned of the risk of drivers becoming de-skilled, or relaxed to the point where they are unable to take over at short notice.

The point was raised that artificial intelligence (AI) will be essential for the introduction of autonomous vehicles because driving is a known, but unpredictable, environment owing to changes in weather; the behaviour of the driver and vehicle occupants and the behaviour of other road users. By applying AI to create a capability for automated responses, the safety of all road users could be improved by improving predictions of accidents and speeding up the vehicle's reaction times.

Autonomous cars also offer the potential to increase productivity by freeing 'drivers' to focus on work-related tasks, child care, or social engagement. They could also offer greater mobility to people who are unable to drive.

Automated vehicles can use a range of sensors including camera, radar and lasers, to collect data about the environment in which they are operating. They then use sophisticated software to localise themselves within that environment, to determine how to proceed to follow their desired path and how to respond to any current or emerging hazards. This information is reconciled with any pre-learned information such as that provided by a digital map, or external information, such as a control centre advising that there is an incident ahead.

Automated driving is highly complex and requires huge amounts of data, which needs extensive validation to ensure that the software-driven vehicles are responding correctly to a variety of different driving scenarios. It is vital to ensure the safety, security, reliability and performance of these vehicles before allowing them onto our roads.

The Fellows discussed current developments in the use of AI within connected and autonomous vehicles and the changes in vehicle design, transport infrastructure, connectivity and driver behaviour that will be required to drive their adoption if they are to become more widespread on UK roads from 2020.

> "Autonomous cars also offer the potential to increase productivity by freeing 'drivers' to focus on work-related tasks, child care, or social engagement. They could also offer greater mobility to people who are unable to drive."

4.1 Human Factors Affecting Adoption of Autonomous Vehicles

Some Fellows voiced the opinion that there is currently a strong technology push for autonomous vehicles rather than a societal pull. They pointed out that human factors are a key consideration. The potential benefits will only be delivered if users' needs are catered for and society accepts and adopts automated vehicles.

There are a number of questions to answer before autonomous cars can become commonplace. The Fellows posed questions on the impact on safety in relation to connected and autonomous vehicles and debated whether drivers can be persuaded to relinquish control over their vehicles and whether this will have a detrimental effect on road awareness and driving skills.

The Fellows also discussed the ethical question of allowing AI to decide who lives or dies in the event of a collision. There are also major considerations around insurance and liability in the event of a collision between an automated vehicle and another vehicle, or with a pedestrian or cyclist. Autonomous vehicles may also encounter aggressive human drivers. An earlier study sponsored by Goodyear[6] had found humans 'bullied' autonomous cars. However, recent research conducted by TRL on behalf of the GATEway project suggests human drivers do not yet know enough about autonomous vehicles to take advantage of them.

In the early phase of adoption, autonomous cars will likely share the existing road network with manually driven cars, posing a risk to other road users that might be impacted by an AI-driven decision to avoid colliding with a truck, bridge or car, in favour of a smaller object. Insurers are concerned over who is responsible in the event of a crash, whether it be the human driver/occupant, or the car manufacturer.

How autonomous vehicles react in this instance may also impact buyer behaviour, as pointed out by TRL Fellow, Professor Paul Newman of Oxford University in the government research report: 'the social dilemma of autonomous vehicles', where he points out that "even though participants approve of autonomous vehicles that might sacrifice passengers to save others, respondents would prefer not to ride in such vehicles".

With the growing use of rules-based AI controlling vehicles, the Fellows also considered the potential impact of losing human discretionary factors, such as giving way at junctions, or allowing confused drivers space to change lanes at the last minute before their junction and other such courtesies that drivers have afforded each other over the years. This represents a significant but not insurmountable challenge to the AI systems managing vehicle movements and will depend on having appropriate training datasets with which to refine perception and behaviours.

Current developments indicate that the future of transport, comprising more efficient, shared use of electric-powered, connected and autonomous vehicles, running on a network of smart roads is not too far off. This vision will deliver a step change in safety, mobility, accessibility and environmental performance. However, this will only be achievable if numerous research challenges can be tackled.

[6] http://news.goodyear.eu/company/future-mobility/will-self-driving-cars-be-bullied/s/20d3c585-19ca-4e60-8b4b-3d2a1c69b912

4.2 Adapting Tests to Include New Vehicle Types

The discussion also turned to how connected and autonomous vehicles might be tested. What challenges are the most pressing? What new capabilities will be required to undertake testing?

The Fellows noted the need for an independent test programme that can examine the performance of an automated vehicle to ensure that the vehicle operates in a safe manner. Ricardo is working on this as part of a new Innovate UK project.

This could lead to a new version of the NCAP safety ratings, where vehicles are measured not only on how well they protect occupants in the event of a collision, but also how capable the vehicle is at avoiding incidents in the first place.

The STATS19[7] national road collision dataset recorded by the police and the RAIDS[8] (Road Accident In Depth Study) data collected by TRL are already used by manufacturers to improve vehicle design and safety for all types of users. More in-depth data on road collisions is required to allow regulators and manufacturers to ensure that new vehicle designs meet future needs.

These questions need to be answered by TRL in partnership with academics, central and local government bodies, infrastructure providers and manufacturers.

> **"**Otto, was the first organisation to transport a commercial shipment via a self-driving truck which travelled 120 miles along a Colorado highway.**"**

4.3 Adapting Infrastructure To Support Connected and Autonomous Vehicles

Trials have been carried out into the use of autonomous vehicles within commercial fleets, to investigate whether freight trucks will be able to travel closer to other autonomous vehicles, with a driver-operated lead vehicle. Doing so offers the potential to make use of slip streaming for fuel economy and to improve the efficiency with which current road network capacity is used. However, the implications for road design need to be considered to avoid structural failure.

Google's self-driving division Waymo and Uber's Otto, are currently trialling self-driving trucks in an effort to make more efficient use of US highways. Otto[9], was the first organisation to transport a commercial shipment via a self-driving truck which travelled 120 miles along a Colorado highway.

The Fellows debated whether fresh infrastructure will need to be built to support electrically-powered, connected and autonomous vehicles. They also talked about the implications for infrastructure providers when it is vehicles that engage with signals, gantries, traffic lights and speed cameras, rather than drivers themselves.

With autonomous vehicles using an array of different sensing systems, re-engineering infrastructure for these systems rather than human drivers could optimise its use. For example, some Fellows posed the question as to how junctions should be redesigned to accommodate crossing traffic, once human courtesy and computer logic share road space.

Future infrastructure will also need to be flexible to accommodate changes in vehicle types and technologies. It is probable that there will be diversification, particularly for electric vehicles, with bikes, mobility scooters and delivery vans becoming optimised for the required range and payload.

[7] http://www.adls.ac.uk/department-for-transport/stats19-road-accident-dataset/?detail

[8] https://www.gov.uk/government/publications/road-accident-investigation-road-accident-in-depth-studies/road-accident-in-depth-studies-raids

[9] https://www.uber.com/info/atg/truck/

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5. Smart Cities and Urban Mobility

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Smart cities involve the integration of multiple ICT, big data and IoT solutions to manage infrastructure and assets. In the transport sector, this includes traffic lights, parking controls and traffic management systems, such as overhead gantry signs, to ease congestion and improve the flow of vehicles around the network.

One of the biggest challenges the UK transport industry faces is meeting demand for road network capacity. Figures show there were 25.8 million licensed cars on UK roads in the third quarter of 2015. SMMT numbers indicate there were a record 2.69 million registered new cars in 2016, up 2.3% year-on-year.

The Office of National Statistics (ONS) reports that the UK population grew to 65.1 million in 2016, while Department for Transport (DfT) figures reveal a record 320.5 billion miles were travelled by vehicles in Britain in 2016: leaving the government with "a lot of catching up" to keep pace with an increasingly congested road network.

In addition to smart traffic management, one solution to the current congestion issues is to encourage or incentivise people to share cars, thereby making better use of existing road infrastructure.

Another solution is to encourage more people to use alternative modes of transport within urban centres, including trains, buses, trams, bicycles, or walking.

One challenge raised by the Fellows is how to incorporate active travel modes, such as cycling and walking, more safely alongside other vehicle types.

The Fellows pointed out that, since cyclists and motorcyclists are at significant risk from larger vehicles, there is a potential benefit from the introduction of sensing and assistance technology on vehicles.

This could make better use of the road network while reducing the risk to riders and occupants of smaller lightweight vehicles, such as quadricycles.

The Fellows discussed how road infrastructure will need to change to accommodate automated vehicles. They also considered the shared use of the existing road network while manufacturers bring electric and autonomous vehicles to market and what legislators might need to consider in order to moderate how driven and driverless, fossil fuelled and electric cars share the roads within busy urban areas.

The Fellows predicted that connected vehicles could result in infrastructure changes such as road signs and traffic lights that are optimised for connected, sensor-rich, autonomous vehicles. Building new infrastructure and introducing new and relevant legislation takes times and investment, and requires consent across all layers of government.

The Fellows agreed that different stakeholders will have to work closely together to ensure that the introduction of new modes of transport in smart cities does not impact accessibility and lead to isolation of certain members of society.

They discussed the fact that while road network capacity will increase, this may not match the increase in demand. There are various strategies that could be followed to avoid further increases in congestion and provide an acceptable level of service.

Research is needed to understand the social and political acceptability of the various options and underpin decisions by government and public agencies. For example, access to road networks could be restricted, or rationed, for certain vehicles or particular users at certain times of day.

The Fellows emphasised that the "User Pays" principle will need to underpin future developments and suggested that occupants of autonomous vehicles might pay a premium to secure a higher speed, or travel in the fast lane, or gain access to a guaranteed route, in a similar manner to the current M6 toll road.

The Fellows also made the point that greater connectivity and autonomous travel may in fact reduce urbanisation by making it easier for people to move away from cities.

The Fellows also talked about the need for smart cities to design link and junction standards that are centred on accessibility for all, in recognition of the fact that judgement and management of junctions changes as we age. Highways England has a target to reduce the incidence of road users being killed or seriously injured by 40% by 2020. The Fellows suggested that improving the transport infrastructure is likely to be the most important factor in reducing collision frequency.

5.1 Changing Driver Behaviour

Despite the current fondness for owning vehicles, cars sit idly for the majority of the time. RAC Foundation research[10] shows the average car is only used for 4% of the time, spending about 80% of the time parked at home and 16% of its time parked at the owner's workplace.

There was a discussion on the potential for traditional car ownership to give way to the 'shared economy', further facilitated by the advent of automated vehicles that collect and deliver passengers before moving on to the next customer.

Uber's success in European cities is already said to have reduced car ownership in certain areas. Whether this translates to a decrease in network capacity requirements is unclear, however. University College London research indicates that car usage in London has fallen from 50% of all trips in the 1990s to 37% of all trips today.

As public opinion hardens against polluting vehicles, sharing short journeys in electric vehicles that produce zero exhaust emissions may become more attractive.

An increase in users participating in shared journeys would reduce the number of cars with just one or two occupants, thereby making better use of existing road network capacity. However, some Fellows suggested that the effect of automated vehicles on road space efficiency will depend fundamentally upon how they are programmed to accelerate, decelerate and manage their position relative to other road users.

[10] http://www.racfoundation.org/research/mobility/spaced-out-perspectives-on-parking

5.2 Transport Solutions for an Ageing Population

The Fellows' discussion then turned to other challenges around road mobility, such as making transport accessible to all ages, abilities and backgrounds. They noted a specific need for future transport solutions to cater for an ageing population who still need to travel but have limited access or ability to do so. ONS estimates that 1 in 12 people will be aged over 80 by 2039. Deteriorating health is the primary reason cited by elderly people who give up driving. However, this is a situation that could be improved through driverless technology.

A 2015 study by Age UK and International Longevity Centre[11] drew attention to the travel difficulties faced by elderly people who do not drive and highlighted the fact that 38% of urban dwellers aged 70 – 74 use public transport weekly, compared to 20% in rural areas. It also found that, in urban areas, 2% of people aged over 65 do not use public transport because none was available. This percentage leapt to 18% for the same age group living in rural areas.

The study revealed that 1.45 million of those aged 65 and over in England found it difficult to travel to hospital, whilst 630,000 found it difficult or very difficult to travel to their GP. However, the same report highlighted the fact that driving remains the most common form of transport for people aged over 70 in the UK, with 68% of households in this age group still at the wheel.

In an ageing society, driver assistance technologies will enable older drivers to continue driving for longer and fully autonomous systems could make personal transport accessible to a range of people who are not currently able to drive.

The report by Age UK and International Longevity Centre[12] acknowledged the role of vehicle design and technology in improving accessibility and mobility for older people, stating "If designed to meet the needs of older people, the increasing use of assistive technology in cars, telematics in determining insurance premiums, and potentially driverless cars, could enable older people to continue driving safely for longer".

The Fellows acknowledged that the increasing use of technology in vehicles and road networks will mean that it is crucial to build infrastructure that is intuitive to use and designed for road users of all ages. Studies of accessibility will need to include better understanding of how our use of transport networks changes as we age.

Ford provided an example of good practice in this respect when it created its "Third Age Suit[13]" to enable its ergonomic engineers to experience joint stiffness, reduced mobility, hearing and visual impairments, so that they could empathise with older drivers and create more suitable seating and controls when designing the Ford Focus.

5.3 Active, Passive and Productive Travel

In the UK, only 8% of men and 3% of women over the age of 65 ever cycle: the lowest percentage in Europe. The Santander bike[14] hire scheme, contracted by Transport for London, is the most high profile initiative to tackle this issue, with 49% of Cycle Hire members reporting that the scheme has encouraged them to start cycling in the capital.

The Fellows discussed the extent to which technology can not only improve road vehicle safety but also create an environment that makes active travel more appealing. Shared, safe, low emission and low cost motorised travel provided by automated vehicles may present a convenient option that counters the extensive efforts made to encourage active travel. However, by the same token, low emission vehicles that behave in a reliable, predictable manner could create an environment in which active travel is more appealing. Careful use of levers around pricing and access could push the agenda more towards the latter position.

Autonomous vehicles will also enable drivers to spend time on more productive or rewarding tasks during their journey. As autonomous vehicles start to be viewed as mobile workspaces, people may elect to travel in vehicles that are more reliable, quieter, better connected, easier to work in and more luxurious. This would also represent an opportunity for car manufacturers to monetise in-car connectivity, entertainment and information systems as they move to become services businesses.

> "Deteriorating health is the primary reason cited by elderly people who give up driving. However, this is a situation that could be improved through driverless technology."

[11] [12] http://www.ilcuk.org.uk/index.php/publications/publication_details/the_future_of_transport_in_an_ageing_society

[13] https://www.youtube.com/watch?v=CEDF9ut7iCc

[14] https://en.wikipedia.org/wiki/PBSC_Urban_Solutions

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6. Intelligent Asset Management

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One of the key challenges for transport stakeholders is that behavioural and technological changes may outpace developments in physical infrastructure, restricting the benefits that can be delivered.

With a rapid pace of change, current investments in infrastructure must provide a system that is adaptable to planned and unforeseen changes. Meanwhile, tunnels and bridges that were built in the Victorian era still form an important part of our transport network. These will need to be monitored and potentially upgraded to carry rail infrastructure that will form part of HS2 and automated fleets of vehicles that are likely to be travelling much closer together.

There was a lively debate on the relative safety and merits of smart motorways which employ overhead gantry networks to implement variable speed limits and dynamic hard shoulders. Some of the Fellows argued whether it is easier to avoid collisions within one's own lane compared to the hard shoulder and pointed out that an estimated 90% of stops on the hard shoulder are illegal.

They queried whether removal of the hard shoulder would reduce the risk of collisions. However, TRL's own research has shown that the implementation of new technology, such as smart motorways, is vital in keeping our networks flowing and can be achieved without increasing overall risk.

In spite of connected systems and autonomous vehicles, the way that humans interact with the transport system will remain a fundamental safety factor. Therefore there will be a continued requirement to design transport networks that are intuitive for new or younger drivers and the elderly to navigate.

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7. Data Science and the Internet of Things

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There are many examples of the use of data analytics to optimise traffic flows, reduce accidents and ease congestion. For example, big data techniques are helping the city of Dublin to improve bus transport and reduce congestion, while a similar project recently started in Toronto, Canada.

The Google-owned navigation organisation, Waze, has numerous partnerships with cities including London, Barcelona, Boston, Jakarta and Rio de Janeiro to integrate its data into intelligent-transportation system traffic-control centres. Drivers thus get detailed, user-generated real-time data, enabling them to avoid bottlenecks, while cities can use information on traffic conditions to respond to emerging situations.

As newer vehicles gain Internet connectivity to enable new features such as in-car entertainment, improved navigation, or monitoring of vehicle performance and component wear and tear, the Fellows' discussion moved to the safety, privacy and cybersecurity issues that must be addressed to enable widespread adoption of connected and autonomous vehicles.

Other than the risk of distracting the driver, most of this connectivity does not affect 'mission' control. However, connectivity does introduce new cybersecurity risks which could put the safety of passengers and other road users at risk in the event that a cyber-criminal took control of a vehicle. It was agreed that cybersecurity and privacy, will become increasingly prominent issues as road vehicles join the Internet of Things (IoT).

There was consensus that manufacturers, government, legal bodies and the technology industry must come together to consider public safety, the environment, cyber-security and the ethics of how humans and machines interact on UK roads. Governments and manufacturers will also need to ensure connected and autonomous vehicle data is managed and secured, throughout transport systems and smart cities that are using this information. TRL may need to develop the capability to test transport data governance on behalf of its partners.

"The shared experience of many connected vehicles will improve the overall data available for predictive and preventive maintenance: helping to prevent accidents."

7.1 The Impact of AI on Driver Competence

As a result of connected and autonomous vehicles, the role of the driver will change. In the short-term, connected vehicles will gather more data on driver behaviour through telematics and IoT-connected sensors, impacting performance and driver attitudes. By tapping into new sources of data, road authorities can attempt to understand and influence journeys, improving the match between demand and available capacity, and reducing congestion.

With greater degrees of autonomy, the role of the driver will change. The Fellows considered the situation when drivers are reduced to becoming part-time operators of vehicles. There are examples of drivers' over-reliance on satellite navigation systems being blamed for driving up narrowing streets or off the end of piers. Similarly, there is a danger that automation of the driving task, where the vehicle is responsible for detecting and responding to hazards, will cause drivers to lose essential skills on which they depend for safe driving. It is highly likely that drivers in cars where the vehicle does some of the driving will be unprepared to take over at short notice.

The Fellows also raised ethical issues, such as drivers overriding controls in order to protect themselves, resulting in the injury or death of other road users. These concerns must be monitored as automation systems are introduced to the vehicle fleet.

The increasing reliance on technology could breed fear and disincentive for some drivers who are less comfortable with the pace of change or have a phobia of technology. The Fellows suggested that, to lessen the risk to all road users, the government may need to update the driving test in response to new technology and driver skill requirements. A new driving test[15] is set to come into force in December, following TRL research for the DVSA, which will include a requirement to understand how to operate SatNav devices.

However, it was also observed that technology could be employed to combat this de-skilling effect, by using telematics within automated vehicles to monitor the driver's performance and provide alerts and in-vehicle training to help maintain the required level of skill that is appropriate for safe driving. If this ongoing monitoring and coaching were to become widespread, it could lead to an overall increase in driver ability across the population.

[15] https://www.gov.uk/government/news/driving-test-changes-4-december-2017

7.2 Maintaining Safety Standards

The Fellows discussed the need for manufacturers, legislators and governments to continue to work together to prioritise public safety and security and jointly develop robust standards as more connected vehicles roll off the production lines.

Safety testing is especially important for autonomous vehicles. It was noted that Google and Tesla cars have continued to crash during testing, resulting in the death of a driver in a Tesla operating in 'AutoPilot' mode in Florida in May 2016. Uber temporarily suspended such tests in March 2017 as a result of a collision in which a human driven vehicle contravened the right-of-way and hit the side of the Uber automated vehicle.

Testing of automated vehicles requires a very different approach. Vehicle behaviours that depend on machine learning and software updates will need to undergo comprehensive virtual, off-street and on-road testing, with continuous monitoring, before we can conclude confidently that a highly or fully automated vehicle is fit for purpose.

On a more positive note, the collection of real-time data, and the possibility of carrying out predictive maintenance, could offer manufacturers and testing authorities an opportunity to gather more insight on current and future vehicle errors. BMW is using a Big Data analytics platform to record "error memories" from new models before they go into production.

The shared experience of many connected vehicles will improve the overall data available for predictive and preventive maintenance: helping to prevent accidents. It was suggested that monitoring components that fail in a gradual and safe way may become part of the system design requirements.

Over-the-air updating will be common as algorithms are improved. However, the Fellows acknowledge that there will always be unexpected failures in this process, as well as difficulties for regulators to overcome to ensure that updates are appropriately documented, approved and in accordance with 'good practice' which is yet to be defined.

Artificial intelligence could allow vehicles to 'learn' road conditions using sensors, as well as assessing the driver's condition via user-owned wearables and manual driver requests from natural language processing algorithms or voice biometrics. Crash avoidance sensors could also be used to alert and aid drivers on their journey.

It was noted that there is an opportunity to gather test information from connected vehicles to improve real-world collision performance and to evolve beyond the standard regulatory tests to which new vehicles are subjected at present.

Security will need to be factored into such tests. The Fellows agreed that once electronic systems take greater responsibility over vehicle controls, the need for cybersecurity testing becomes ever more important.

Cybersecurity researchers have compromised a number of connected and autonomous cars to date, exploiting everything from basic software flaws to entertainment features, with Chrysler recalling 1.4 million vehicles following one such incident in 2015.

The Fellows discussed a scenario whereby security failings could lead to whole fleets of connected and automated vehicles being disrupted. It was suggested that security improvements might be achieved by cross-validating sensor inputs within the vehicle and with external sensing equipment, to corroborate the behaviour and actions of the vehicle. This would make it more difficult for hackers to carry out co-ordinated attacks on multiple vehicle control systems without detection.

Ethically, there are far more questions than answers as cars become shared, connected, self-driving machines which contribute to the collection of big data and rely upon a variety of technologies, such as 5G networks, machine learning algorithms and artificial intelligence.

7.3 Data Use and Governance

In a scenario where smart road networks and connected and autonomous vehicles are run by computer algorithms making decisions on our behalf, the Fellows discussed at length who might be held liable when an accident occurs.

Returning to their earlier point about reducing collisions by improving the driving environment, the Fellows discussed how road infrastructure could tap into shared accident investigation datasets, such as STATS19 and RAIDS, to reduce vehicle speeds automatically in response to adverse driving conditions, or to divert autonomous vehicles away from collision locations. This would require relevant data to be provided to road authorities by vehicle manufacturers: a move that is likely to require regulation.

The Fellows also talked about the possibility of linking transport infrastructure to open government datasets, such as WebDAS and geomatic databases such as the Environment Agency's LIDAR[16] dataset, to inform drivers of current traffic conditions and terrain, so that they can adjust their route, speed and fuel stops accordingly. TRL holds a wealth of test data and could also contribute to transport datasets. The Fellows discussed the possibility of a data analyst exchange programme, to facilitate sharing of datasets between stakeholders.

With connected cars, smart gantries, traffic lights and signals increasingly collecting huge amounts of data about driver activity, traffic flows, road network congestion and accident locations, the Fellows also considered the privacy issue of who controls and owns this data. If we are monitoring the vehicles to improve vehicle maintenance and public safety, do we also have the right to monitor the location and driving behaviour of human occupants? How do we protect their privacy?

Manufacturers, in their bid to become services companies, will likely look to monetise driving data. McKinsey has forecast that automotive data revenues will reach $750 billion by 2030. However, this strategy conflicts with previous research which has shown that UK connected car owners believe that the data their vehicles collects belongs to them[17], further highlighting the importance of safeguarding data and protecting the privacy of the travelling public as vehicles become more connected.

> **“**It was suggested that security improvements might be achieved by cross-validating sensor inputs within the vehicle and with external sensing equipment, to corroborate the behaviour and actions of the vehicle.**”**

[16] http://environment.data.gov.uk/ds/survey/#/survey

[17] https://internetofbusiness.com/uk-drivers-want-more-control-over-connected-car-data/

8. Transport 2020 – Are We Nearly There Yet?

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The UK is leading the charge and there are a number of autonomous vehicles being trialled in an effort to understand the issues and impacts of them being introduced to our highways.

FiveAI's Streetwise trial in London and Oxford aims to offer a shared self-driving car service, which commuters can order via a mobile app. Streetwise has the involvement of Direct Line, TfL, The University of Oxford and TRL and is working to create new insurance policies and safety standards governing autonomous vehicles.

Driven, the self-driving technology collaboration between Oxbotica, Oxford Robotics Institute, Oxfordshire Council, Telefonica, Race, Nominet and TRL is working to develop an autonomous vehicle shuttle service linking Oxford and London. Both Streetwise and Driven have received funding from the UK government's Industrial Strategy Challenge Fund.

Intertwined with this, is TRL's UK Smart Mobility Living Lab[18]. Located in Greenwich, the Living Lab provides a real-life environment where connected and automated vehicles and new mobility systems, services and processes can be safely developed, evaluated and integrated with the local community in a megacity context.

TRL also leads the GATEway project[19], an £8 million research project funded by government and industry to understand and overcome the technical, legal and societal challenges of implementing automated vehicles in an urban environment.

A key benefit of testing in Greenwich is that it currently supports a rich array of transport modes including overground and underground rail networks, pedestrian areas, highways, cycle lanes, cable car and river transport. This allows TRL researchers to test how ultra-low emission and automated vehicles will interact with and complement existing modes of transport in a real-world environment.

These projects aim to provide evidence-based research to accelerate the entry of automated, driverless car technologies to the UK market, along with the required insurance and safety protocols.

"TRL also leads the GATEway project, an £8 million research project funded by government and industry to understand and overcome the technical, legal and societal challenges of implementing automated vehicles in an urban environment."

[18] http://uklivinglab.trl.co.uk/

[19] https://gateway-project.org.uk/

TRL Academy

Conclusion – Working Together to Influence the Future of Transport

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The assembled experts acknowledged that technology and society are constantly changing, with the result that no-one can be entirely certain what transport will look like beyond 2020.

The Fellows were in general agreement that current challenges of road network availability, accessibility, congestion, safety, emissions and air quality, can be countered through new and emerging technologies. However, successful delivery depends upon collaboration between government bodies, manufacturers, transport operators, infrastructure providers and academics.

The importance of related industries is growing with the energy, communications and insurance sectors playing an increasingly critical role. TRL's role in transport innovation can help to bridge gaps between these stakeholders to help find new applications and approaches that deliver a safer, cleaner, more affordable, more accessible and more efficient transport system.

Solving mobility challenges requires a mix of technological advances and commercialisation, funding, smart government policies and business model innovation to truly realise the benefits expected from electric, connected and autonomous vehicles.

The Fellows acknowledge an ongoing requirement to develop infrastructure and vehicles that work with young new drivers and the elderly to improve accessibility and safety and to facilitate different travel modes and vehicle types, particularly within cities. We must assess how infrastructure might be adapted to suit the needs of new vehicle types to ensure that we continue to reduce risk, improve safety and comply with governance and regulations.

Politicians must help to drive initiatives to ease introduction of new business models, new players and modes of transport. In particular, the Fellows emphasised the need to enable organisations to undertake pilot trials and exploratory studies without fear of failure – where we can learn lessons quickly and move on. There will also be a requirement for testing and governance to evolve as new modes of transport emerge.

> "It was pointed out that TRL has the potential to create more shared value from its research. This should extend to multifaceted collaborations with technology, scientific, societal, financial and commercial organisations."

On infrastructure, there is a need for a better evidence base. For example, the Highways England 'Road to Growth' is focused on build initiatives. However it is not clear where the research is coming from to explore the impact of those initiatives. From a cost perspective, industry needs better evidence-based techniques to understand what 'good' design looks like, and implementation strategies, as well as cost benefit models. Linked to this, we need better understanding of structural maintenance of the highway through intelligent asset management.

The Fellows recognised that road safety research needs to embrace city and local authority perspectives as new models of transportation become mainstream. There is a need for more consideration for phasing and delivery of these activities.

The Fellows agreed that more guidance is needed in the area of behavioural science to understand how humans engage and interact with transport systems as technology impacts transportation methods. This will be fundamental and ever-changing.

The transition to autonomous vehicles also brings about a raft of new skills that are required, especially around artificial intelligence, machine learning and big data. Car manufacturers are already hiring in these areas, especially for software developers and data scientists.

It was suggested that TRL could make its own datasets available and initiate a data analyst exchange programme, to facilitate the sharing of transport and mobility insights across key stakeholders. It was pointed out that TRL has the potential to create more shared value from its research. This should extend to multifaceted collaborations with technology, scientific, societal, financial and commercial organisations.

Using its scientists' expertise in bringing together disparate data to understand transport issues and impacts, TRL could act as an independent source of business intelligence to all stakeholders. As an example, discussions highlighted the potential for the joint operation of a smart city sensor array, whereby multiple Living Lab projects could be linked, to investigate the effects of new modes of transport or traffic management systems at different locations and scales of operation.

In conclusion, electric, connected and autonomous vehicles hold the key to a sustainable model of transport and mobility that addresses the current air quality crisis in our towns and cities, while enabling accessibility. New modes of transport have the potential to transform all of our lives. Therefore, a continued, collaborative effort is required to query and rigorously test the full spectrum of impacts of transport and infrastructure changes, before they achieve mainstream adoption.

We thank all the Fellows who were able to contribute to the meeting and share their thoughts. There is huge potential in the possible collaborations between TRL and the Fellows, working closely with their respective organisations, to consider the full spectrum of impacts of associated with the anticipated changes to transport and mobility ahead.

To facilitate this collaboration we aim to provide an open forum for discussion and debate, along with physical facilities, where new vehicles, materials, technologies and infrastructure can be queried and rigorously tested, with sufficient evidence gathered, and interventions suggested, before they are introduced to our road and rail networks.

By working together and delivering rigorous and robust research, we can assist in the development of new technologies, inform regulators and policymakers about the potential benefits of such systems and evaluate their performance in virtual, controlled and real world settings.

As ever, new technologies provide us with options for the future – we need, as a society to determine how those technologies are implemented to improve our lives. TRL, working collaboratively with our Academy Fellows, will remain a significant contributor to delivering the future of transport.

About TRL and the TRL Academy

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Based near Wokingham in Berkshire, the Transport Research Laboratory (TRL) is a centre of excellence for independent, innovative research into future transport.

Our mission is to challenge established methods and thinking and influence the transport sector in order to drive sustained reductions in:

- Fatalities and serious injuries
- Harmful emissions
- Barriers to inclusive mobility
- Unforeseen delays
- Cost inefficiencies

Through our innovation and development centre, the TRL Academy, we provide organisations with the evidence base needed to enable future innovation in transport. We also offer technology and software solutions for surface transport modes and the related automotive, motorsport, insurance and energy markets.

Our core areas of expertise include:

- Transport safety
- Vehicle engineering and simulation
- Investigations and major incident forensics
- Human factors and behavioural science
- Intelligent transport systems
- Infrastructure asset management
- Sustainability and climate change

TRL was established in 1933 as part of the UK Government's Transport Research Laboratory. Now a private organisation owned by a non-profit distributing foundation, TRL has more than 1,000 clients across 145 countries.

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