



Advancing autonomy in transport

Identifying the opportunities for cross-modal learning across the aerospace, automotive, rail and maritime sectors.

theiet.org/transport

— About this report

The Institution of Engineering and Technology's (IET) Cross-Modal Autonomy Working Group consists of experts in autonomy from across the transport modes. Supported by IET staff, the group has developed a programme of work leading to the publication of this report.

This included a workshop which brought together experts from academia, government and across the transport industry – equally divided between road, rail, air and maritime – to discuss the potential benefits of the transport sectors working closely on matters relating to autonomy. The participants also took part in a series of sessions that explored four imagined problem scenarios involving autonomous systems – again, split across the transport modes. These problem scenarios were designed to stimulate conversation and captured the potential issues that could arise if the transport sectors do not learn from each other. They have been included in this report along with a real-world example, the Boeing 737 MAX 8 incidents, which have raised awareness of some of the issues that potentially arise with increasing levels of automation in the control of vehicles.

The group worked closely with IET staff to pull the content from the workshop together and translate it into this report, which presents an overview of the discussions that took place, along with the participants' and working group's recommendations on what the next steps should be to bring about a more collaborative approach to autonomy between the modes. The report follows on from the IET's last paper on cross-modal learning¹, published in 2016, which tackled the issue on a more sector-by-sector basis.





Contents

1. Executive summary	4
2. Introduction	6
3. The benefits of cross-modal collaboration	7
4. The challenges to overcome	8
5. Outlining the early opportunities	10
Development of safety arguments	10
Case Study: Boeing 737 MAX 8 Incidents	12
Having the human as part of the system	13
Problem Scenario: Maritime	14
Narrowing the digital skills gap	15
Problem Scenario: Automotive	16
The approach to migration, and living with legacy systems	17
Problem Scenario: Rail	19
Ethics and the benefit to society	20
Problem Scenario: Aerospace	21
6. Conclusion and next steps	22
7. Acknowledgements	23

1. Executive summary

Society stands to gain significantly from the introduction of autonomous transport systems, which will bring about numerous benefits in areas such as safety, flexibility, independence, economic value and sustainability. However, there are a number of challenges that have to be overcome, and opportunities grasped, before society is able to reap these benefits.

The Institution of Engineering and Technology (IET) brought together experts from academia, government and across the transport industry – equally divided between road, rail, air and maritime – for a workshop to discuss the potential benefits of the transport sectors working closely on matters relating to autonomy. They also explored the challenges that can be tackled through cross-sector collaboration and the opportunities that inter-modal working can present.

The benefits of cross-modal collaboration

There are significant benefits to be had from increased cooperation between the sectors at every level, including:

- **Improved safety** through a common approach to developing safety cases, ensuring a consistent approach to safety standards and to extract a cost saving benefit
- **Integrated safety and operations** by streamlining the touch points between modes from both a safety perspective (e.g. cars and railway level crossings, flying cars) and efficient integration (e.g. freight)
- **Better network efficiency/capacity** via improved integration between transport modes
- **Reduced variability in performance** through the increased accuracy of automatic control
- **Addressing the climate emergency** by sharing knowledge, science and approaches in improved efficiency of operation

The challenges to overcome

All transport sectors recognise the potential benefits from the introduction of autonomy and the barriers to introduction that they are facing are similar. There are a number of questions that will need to be answered in regard to the common challenges, such as:

- **Where does responsibility for safety lie?** As the decision-making elements of the transport system take on a higher level of safety criticality, responsibility shifts further away from the vehicle occupants to the design and maintenance engineers
- **How do we achieve migration through mixed-fleet operation?** Finding a safe and affordable way of operating mixed fleets of manned and unmanned vehicles from multiple generations is a major obstacle
- **How will legislation and regulation support the social benefit?** Autonomy will require changes in legislation and the development of new regulations, which will need to keep pace with the rapidly evolving technology
- **Where does responsibility for ethics lie?** Ethical dilemmas range from the allocation of responsibility for the action of a system, through the human rights of intervention to the actual decisions made by the system in the event of an impending accident

The early opportunities for increased cooperation

There are several early opportunities that government and industry need to grasp in order to accelerate the development, reduce the cost and maximise the benefit of autonomy across the modes,

- Development of safety arguments
- Having the human as part of the system
- Narrowing the digital skills gap
- Managing migration to autonomy, and living with legacy systems
- Safeguarding ethics for the benefit of society

Conclusions and next steps

This new system of cross-modal collaboration should be driven by government with the support of industry. The IET recommends that government progresses the following three actions:

1. Work with professional bodies such as the IET to raise awareness of the challenges and opportunities for cross-modal learning within industry.
2. Form a cross-government and cross-engineering professional body working group to develop the opportunities for cross-sector collaboration outlined in this report.
3. Facilitate cross-sector collaboration and knowledge transfer through the implementation of an Autonomy Accelerator.



2. Introduction

The wider introduction of autonomous transport systems will create significant benefits for society in areas such as safety, flexibility, independence, economic value and sustainability.

Automatic or remote operation of vehicles is not a recent development, particularly in the air and rail sectors. Although these systems can differ greatly, a common feature is their ability to operate in segregated or heavily controlled space to minimise the risk to people and property. This has led to a rise in the use of unmanned military aircraft, undersea vehicles and automated metro systems, for example, yet the full exploitation of their value in all sectors has been limited by the inability – technically and legally – to let them 'off the lead'.

Despite their many differences, the air, rail, road and maritime sectors all face the same basic technical, social, legal and ethical challenges when it comes to implementing autonomy – albeit starting from different

baselines and with varying degrees of complexity and scale. They must all be able to i) offer some form of collision avoidance; ii) deliver secure and high-integrity communications with the infrastructure; iii) ensure vehicle health monitoring and degradation management; and iv) be able to safely handle all contingencies. These technical solutions also have to conform to industry standards – meeting both national and international regulations and legislation – and be insurable to have a positive impact on society. A systems approach is needed to connect all the different disciplines, manufacturers and nations together.



The Airbus Vahana. Image courtesy of Airbus A³

3. The benefits of cross-modal collaboration

There are significant benefits to be had from increased cooperation between the sectors at every level, with some specific early opportunities to be addressed. These will be discussed further later in this report:

1. Development of safety arguments
2. Having the human as part of the system
3. Narrowing the digital skills gap
4. The approach to migration, and living with legacy systems
5. Ethics and the advantages to society



The autonomous submarine Autosub Long Range, affectionately known as 'Boaty McBoatface'. Image courtesy of Povel Abrahamsen (British Antarctic Survey).

All transport modes share the same basic systems architecture with each requiring sensors for situation awareness, a processing capability, actuators to control the vehicle and connection to the infrastructure. In a manned vehicle these functions are largely undertaken by the human but with increasing automation support (e.g. GPS, anti-lock braking, lane assist, etc. in a car); however, in a fully autonomous system these will all be undertaken by the vehicle. Most of the legal, social and ethical issues are common across the modes with the technical challenges differing only in the detail of the application.

There is, therefore, a strong case for examining the benefits of cross-modal learning and co-development as well as the potential efficiency benefits of cross-modal integration.

The positive outcomes that could result from closer working across the transport modes include:

- **Improved safety** – through a common approach to developing safety cases, ensuring a consistent approach to safety standards and to extract a cost saving benefit
- **Integrated safety and operations** – by streamlining the touch points between modes from both a safety perspective (e.g. cars and railway level crossings, flying cars) and efficient integration (e.g. freight)
- **Better network efficiency/capacity** – through improved integration between transport modes
- **Reduced variability in performance** – through the increased accuracy of automatic control
- **Addressing the climate emergency** – through the sharing of knowledge, science and approaches in improved efficiency of operation

4. The challenges to overcome

All four transport sectors recognise the potential benefits from the introduction of autonomy and the barriers to introduction that they are facing are similar.

Autonomous operation in all transport modes will require on-board intelligence even if only to cater for a temporary loss of communications with the external infrastructure. The infrastructure guidance point could be a remote pilot, a track signalling system or a traffic management system. Additionally, any failure in communication has to result in a known degraded state that needs to be communicated to the user, and then a fail-safe system that brings the operation to a safe termination or allows a graceful return to full operation with minimal operator intervention.

Although the principle requirements are the same, there are significant implementation differences between transport modes on how this can work. For instance, the time for handing back control to a human operator can vary significantly from seconds on the road to minutes in the air and sea. The response to failure also poses different challenges over how to bring the vehicle to a safe resting place. Air and undersea vehicles have the advantage of three-dimensional and fairly uncluttered space for collision avoidance whereas above water, road and rail vehicles have more limited freedom, with road being by far the most challenging.

Further complexity is that automated vehicles will, in almost every case, have to share their environment with the current 'manned' vehicle stock. Whilst initially it has been practical to use segregation for rail, sea and air, this would require major infrastructure investment for roads.

Autonomy will drive down the cost and risk for the users but will increase the challenges and the responsibilities of the engineers. Currently all the sectors see the advantages of autonomous systems and are investing in research and development, although largely independently and for competitive advantage. The benefits can be maximised and the risk reduced by sharing as much learning as possible across the sectors, developing common systems architectures and standards, and ensuring that the necessary skills and accreditations are in place.



Photo: UK Autodrive, Rui Vieira/PA Wire

Examples of common challenges

Where does responsibility for safety lie?

As the level of autonomy increases, the responsibility for safe operation is transferring from the driver/pilot to the vehicle and infrastructure systems. As the decision-making elements of the transport system take on a higher level of safety criticality, responsibility shifts further away from the vehicle occupants to the design and maintenance engineers. This requires a rigorous approach to system and software standards, validation methods and the approach to vehicle certification. The responsibility for maintaining continuing air/road/rail/sea-worthiness for both the vehicle and its connecting infrastructure through its whole life is a significant challenge.

How do we achieve the migration through mixed-fleet operation?

The rail and the defence sectors have been able to introduce varying degrees of unmanned or remotely-piloted vehicles by segregating operations from conventionally manned vehicles. This will not be economically or socially acceptable for the more general adoption of autonomous vehicles other than maybe in the more remote and sparsely populated global regions. The challenge is to find a safe and affordable way of operating mixed fleets of manned and unmanned vehicles from multiple generations. This is both a technical and social challenge. How will public acceptance be managed? In complex situations, at least initially, it will almost certainly be necessary for the human to be able to take back control of the vehicle. How will the human know when this is necessary and how will gradual loss of 'driver' skills be addressed?

How will legislation and regulation support the social benefit?

Autonomy is a disruptive technology but with very significant potential economic and social benefits. It will require changes in legislation and the development of new regulations, which will need to keep pace with the rapidly evolving technology. This requires positive, clear and consistent support from government over an extended period. The opportunity is to achieve a fully integrated transport system that should deliver a higher quality of life with significantly reduced environmental impact. How will this common strategy be developed and delivered?



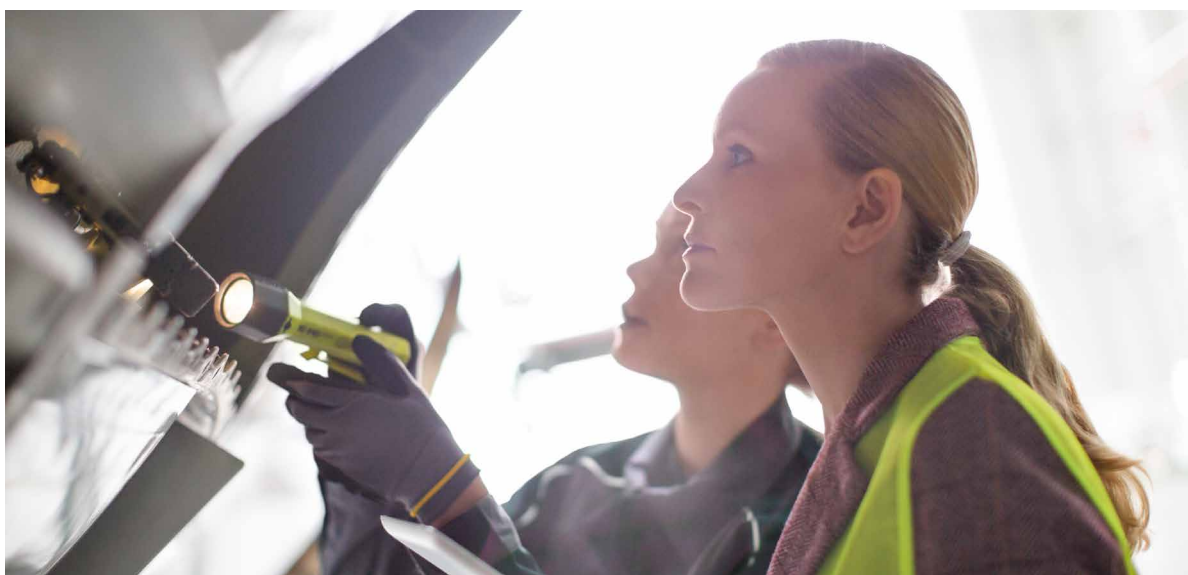
Where does responsibility for ethics lie?

Autonomy in any sector raises ethical dilemmas. In transport these range from the allocation of responsibility for the action of a system, through the human rights of intervention to the actual decisions made by the system in the event of an impending accident. The current large discrepancy in acceptable safety levels across the different transport modes is one dilemma that autonomous systems will need to address. Who should be responsible for the decision logic in an autonomous vehicle and for the acceptable failure rate?

5. Outlining the early opportunities

If there are clear benefits to a joined-up approach involving each of the transport sectors, how can this be achieved? This section explores the early opportunities that government and industry need to grasp in order to accelerate the development, reduce the cost and maximise the benefits of autonomy.

1. Development of safety arguments



Of the transport sectors, road is probably the most immature in terms of progressing the safety arguments. However, there are obvious differences between aerospace and rail, where aerospace places a large emphasis on the initial 'airworthiness certification', followed by rigorous maintenance procedures to ensure that the integrity is maintained.

Railways have a similar but different approach where a safety argument must be accepted by an infrastructure manager (e.g. Network Rail or Transport for London), which have already demonstrated to the national regulator (Office of Rail and Road) that they have an appropriate safety management system in place.

In the maritime sector, in a similar way to air, safety is based upon adherence to Classification Society requirements (broadly equivalent to the airworthiness certification) and ongoing ship surveys through the life of the vessels under the jurisdiction of the International Maritime Organization (IMO) – again, like aerospace, to maintain that classification.

It is also important to note that in the disciplines of marine, aerospace and rail, these autonomous arrangements are treated as systems. This involves integrating infrastructure with the communication system and vehicles, and most importantly, in all cases (even when fully automated), the key operators (e.g. pilots, drivers, signallers, air traffic control, harbour masters etc.) are all highly skilled persons demonstrably capable of managing the task under normal, degraded and emergency conditions.

However, the road 'system' at present is quite disparate, with infrastructure under different owners (e.g. Highways England, County and Local Councils) and, except for the emergency services, all the operators – apart from having demonstrated the appropriate skills at some point in their life – are unskilled. Whilst the road sector operates a risk-based approach to application of their schemes, this is mostly to demonstrate an argument to proceed, and is mostly CDM² (Construction Design and Management) - based to protect their workers. Rarely are any of these risk

² Health and Safety Executive Construction (Design and Management) Regulations. <http://www.hse.gov.uk/construction/cdm/2015/index.htm>

assessments articulated into a form of safety argument. Certainly, in the road area, the combination of systems required to achieve a successful autonomous system has never been approached from a systematic view point. The safety work that has been performed is generally with a very limited scope, very parochial and rarely at a system level. Similarly, the road sector does not carry out post-crash and near-miss investigations through an independent accident investigation branch as is undertaken in other modes, including the approach to transparency in reporting followed by the Air Accident Investigation Branch.

A key component of the autonomous system is the vehicle, whether it is a car, ship, train or aircraft. Whilst the motor industry supplies vehicles with large amounts of software (some estimate a typical car has ten times the software in a commercial aircraft) very little of it has any safety-critical element as most car systems are defined as 'driver assistance', thus reducing the need for integrity. For a fully autonomous vehicle this will have to change, where certain functions require a very high level of safety integrity. The aerospace and rail sectors have considerable experience in safety-critical systems and particularly those functions that are required to operate on the vehicle. The key difference with autonomous vehicles is that the operator in these vehicles may have no training and that will need to be

reflected in how the system deals with degraded and emergency modes. This will have to be a key feature in any system-level safety argument.

We should also think about how we can manage the process of people and machines learning together in a truly adaptive system. Existing methods to assure and qualify systems could be complemented by educational approaches to understand how learning and development can be designed and included. The detail of the safety case will depend on the application but the principles should be common.

There is a need for innovation in engineering processes and practices as technologies such as adaptive systems (e.g. machine learning) are introduced. Standardisation of processes and techniques is required in particular for assuring autonomous systems that recognise that the system will continue to evolve its behaviour in use and will need to interact with other vehicles (of many varieties) and infrastructure that may also contain AI and adaptive technologies.



Case Study Boeing 737 MAX 8 Incidents



The Boeing 737 MAX 8 incidents have raised awareness of some of the issues that potentially arise with increasing levels of automation in the control of vehicles. Without speculating on the results of the investigations ongoing into the two accidents it does highlight some of the issues raised in this report.

The depth of safety analysis performed when quoting "grandfather rights" and emergent properties when making changes to existing systems, either for the vehicle or the infrastructure, have to be carefully assessed. During the introduction of new elements into a legacy system, design assumptions made on the overall systems performance at the functional interfaces requires full and in-depth analysis to determine which systems have been directly affected and those that potentially have been exposed to indirect influence. The analysis of any new system design in isolation can lead to integration issues; this is especially pertinent when a number of legacy systems have been inherited from a previous variant. This will inevitably arise with the introduction of greater or full automation into legacy systems.

Where the response of the pilot/driver is time-critical, as in the case of an aircraft flying at low level shortly after take-off, the safety argument either has to dictate a very high integrity system

not subject to single point failures or a human factor design that gives the pilot/driver unequivocal advice on the nature of the fault condition and the correct remedial action. The human factor design and training system is part of the safety assessment. Where the human performance (e.g. reaction time, sustained close monitoring) cannot meet the safety target, the system has to be designed to safety critical standards. The introduction of new functionality into an existing type and released as a new variant needs to be well documented and provided to the operators, complemented with training for operators. Training should always look at the new or changed functionality and include failure scenarios such as loss of or degradation of the new functionality as a minimum, and trained for in simulation.

The emergent properties link between these Boeing accidents is clear when many lives are sadly lost in high profile newsworthy crashes. But should an emergent behaviour of a system occur in, say, 300 separate fatal road accidents spread across the globe over several years, with a similar net total loss of life, it may not be so easy to detect. Hence there is a need to share – in the style of aviation – CAV accident information not just about the vehicle but the road and surrounding circumstances "system of systems", as well as near-miss data.

The challenge of understanding these interactions does appear to generalise across different modes of transportation, and is likely to increase as levels of autonomy increase.

The investigation into the 737 MAX incidents will continue for some time and one thing that is certain is that the root cause(s) will be complex and cover many areas. Industry and regulators needs to learn from the aftermath of these accidents, especially in an era when air travel is on the increase resulting in demand to increase the number of aircraft available to operators. Industry is under pressure to drive forward the advancement in new technologies that complements existing technologies to satisfy the demand at levels never experienced in the industry before, introducing even great pressures on all involved.

2. Having the human as part of the system



We live in a world of rapidly changing technologies. These are beginning to fundamentally change the ways in which people, machines and technological systems interact. The evolving relationship between people and technology will play a key role in the future of transport.

Emerging technologies, such as augmented and virtual reality, artificial intelligence (AI) and data visualisation offer opportunities to rethink these interactions in light of the parallel transformation of mobility. Rapid changes in transport technology, increasing volumes of information, along with new visualisation and augmentation techniques will completely change traveller experience. This will extend beyond the 'mechanics' of transport and traditional single-sector perspectives (e.g. vessels, vehicles and trains) into the interconnected digital environment. It is paramount that solutions are seamlessly aligned across all transport domains in order to deliver coherent mobility services. These should be designed from a user's perspective, informed by a rich understanding of how they will experience the journey, to achieve the modal shifts required.

This transformation is occurring at the same time as changing demographics and 'digital skills'. It can be argued that this characterises people into three broad groups: digital natives³, digital immigrants and digital inventors. These distinctions reflect people's familiarity and ease with which they embrace technology rather than their age. The complexity that this poses from a 'whole system' perspective highlights the need to emphasise interdisciplinary approaches to ensure that new transport solutions are developed that meet the requirements of these different target user groups. In a transport context these technologies could provide

traveller support during journeys, such as helping people navigate the transition between different modes of travel. Other aspects of travel will also change. If more elements become automated, our current patterns of interaction with 'drivers' or other customer support staff will disappear. This raises many questions:

- Would this create a 'better' mobility service?
- How should such a transition be managed?
- How will people relate to machines, in terms of trust and acceptability?
- What would this mean for the design of new transport solutions?

We should consider these questions, and others, from many perspectives, not least the travellers'. This will enable future transport systems to be designed, developed and deployed in such a way that people trust in the suppliers, the service providers, the engineering and technology (i.e. in the systems and the vehicle). Such trust and acceptance will need to be developed and evolve over time. We should consider how we ensure that the solutions are inclusive and accessible to as many as possible. They should be relevant to a diverse multi-generation population, rather than narrowly optimised for those with more adept digital capabilities or the life patterns of younger generations. There will definitely be a need to strike a balance.

There has to be a fundamental rethink of the jobs and skills required in the transport sector. New roles will emerge – driven by changing business models – along with new people-machine relationships and a fundamental transformation of transport infrastructure. There is a need to think more broadly than system engineering diagrams to consider what a future transport system could look like if designed using completely different frames of reference. Human factors, behavioural science and the arts can all bring different viewpoints.

There is no doubt that society is facing a major transformation of transport, enabled by technology. To reap the benefits, it is crucial to address and possibly disrupt traditional notions of transport and the associated business models. Probably the hardest task of all, however, is the need to ensure the proactive management of the transition period while these systems are introduced, in order to maintain the trust of the travellers using them. This will take time – probably many decades – but it must run at the pace that society at large can deal with, not at the pace of the technologists.

³ The term **digital native** describes a person that grows up in the digital age, rather than acquiring familiarity with digital systems as an adult, as a **digital immigrant**. [Wikipedia]. We have used the term **Digital Inventor** to cover those that entered the Information Technology industry as it developed.



Problem Scenario – Maritime

A large autonomous container ship negotiating the Solent during Cowes Week suffers a major communication loss, possibly from a lightning strike or electrical storm. The ship is under 'remote pilotage' rather than full autonomy and does not respond to supervisor requests. Weather and sea conditions are such that it would be high risk to try and disembark people by sea transfer or helicopter.

How to address it

- It is increasingly the case that expecting crew members to be sufficiently skilled to 'jump in', assess the situation and rapidly take over when the vessel's autonomous systems can no longer cope is possibly unrealistic. Air France Flight 447 and Lion Air Flight 610 are examples of the difficulty a crew faces in assuming manual control after automatic systems have malfunctioned.
- The vessel must be designed go through a process of degraded functionality as failure of the communications links to the remote supervisor sets in.
- The adoption of autonomous operation without sufficiently trained crew on board would have to be dictated by conditions such as weather and the levels of other traffic, (i.e. during Cowes Week). When there is a likelihood of extremely poor weather, or traffic in the area is expected to be unusually heavy, or navigation unusually complex, then the presence of human pilots on board would need to be mandated.
- The vessel would be expected to employ fall-back modes to safely come to a halt, or revert to some pre-ordained behaviour, or navigate away from other craft as the on-set of system failure becomes apparent.
- Large vessels operating under the mode described here would not happen in isolation. As with many other forms of transport, the degree to which the autonomous vehicle is also a connected vehicle is important, as this would dictate the degree to which surrounding craft would be aware of the unfolding situation and be able to react to it.
- Will 'remote pilotage' ever be viable – with a reliance on communications links and a sufficiently high confidence in this – to permit the removal of all crew from the vessel? At least it may be the case that this mode of operation only becomes viable when ships are able to operate fully autonomously (equivalent to SAE Level 5⁴ for road vehicles).

⁴ <https://www.sae.org/news/2019/01/sae-updates-j3016-automated-driving-graphic>

3. Narrowing the digital skills gap



Autonomous systems are a disruptive technology and their advancement will require an overhaul of the skills landscape and shifting the focus more towards digital skills.

Using the example of the automotive sector in the UK, the production of connected and autonomous vehicles (CAVs) is predicted to create more than 37,000 jobs by 2035, according to a 2018 study from the Centre for Economics and Business Research (Cebr) and Oxford-based driverless car start-up StreetDrone⁵, but unless the current skills shortage is urgently addressed, there may not be enough workers with the right skills to fill these vacancies.

With both the future of mobility and artificial intelligence at the heart of the Industrial Strategy, it is evident that the UK is striving to be a leader in the area of connected and autonomous vehicles, but this cannot happen unless significant progress is made to improve the skills pipeline.

Having individuals that possess digital skills and proficiency in areas such as systems engineering, programming and software development will be crucial for getting these vehicles on the road and making the necessary infrastructure changes to ensure those roads are ready for CAVs. Cebr and StreetDrone's research revealed how information technology and telecommunications professionals will be needed to handle the vast amounts of data that will be produced, and new types of skilled manual workers will be required for the assembly of the many new electrical components that will be involved, such as advanced

sensors and cameras. This may be a challenge for a sector that has historically relied on more 'traditional' engineering skills, but it is an obstacle that will need to be overcome if the benefits that autonomy promises are to be realised.

Furthermore, as many of the digital skills needed are set to become equally desirable across other areas of engineering, transport may find itself competing with other sectors for the brightest graduates and apprentices. Out of all the employers interviewed for the IET's latest Skills and Demand in Industry Survey⁶, representing a wide variety of sectors, nearly a third (30%) stated they had firm plans to introduce or extend their current use of digital technologies in the near future, and 75% of those that do plan to introduce or increase their use of digital technologies need to develop new skills in their existing workforce.

Such a high level of demand clearly presents an excellent opening for young digitally-trained engineers looking for a future-proof field to specialise in, like autonomous transport. This trend will also open new doors for experienced engineers to reskill or upskill, combining their existing talents with these new skills to take advantage of the opportunities created.

Because many of the digital skills necessary to work with autonomous systems will be applicable across the various modes, it should be possible – and most likely beneficial – to create an environment whereby workers are able and perhaps even encouraged to move between them, although this may take some time to implement.

Although there is a lot of work to do to close the digital skills gap, the higher education sector has started to respond to these changing skills demands. Many universities have been introducing courses designed to equip students with the kinds of digital skills that would make them suitable for new roles that are beginning to appear across the engineering sectors. However, some institutions have gone a step further, launching degrees specific to autonomous transport, such as The University of Salford's BEng Automotive and Autonomous Vehicle Technology, which started in September 2018, and Cranfield University's new MSc in Connected and Autonomous Vehicle Engineering (Automotive), which is expected to be rolled out from the 2019-2020 academic year onwards, subject to university approval.

⁵ 'Out of the Slow Lane: Research into the employment impacts of the UK's CAV industry and the skills available to support this sector' <https://streetdrone.com/press/out-of-the-slow-lane/>

⁶ <https://www.theiet.org/impact-society/factfiles/education/iet-skill-surveys-2006-present/iet-skills-survey-2017/>



Problem Scenario – Automotive

A recent over-the-air software update designed for smoother automated vehicle following has a bug, or has possibly been hacked, causing most automated vehicles to enter a degraded operation/safety mode limiting speed to 30mph and a 2.5-second headway. With 60% of vehicles now automated, and most of those drivers not insured for manual takeover, the result on interurban highways is congestion, chaos and frustration. Even manual drivers find most roads including B-roads and diversions clogged.

How to address it

- Different vehicles could have different bugs in the systems due to variations in the way standards are implemented by separate organisations/manufacturers. Software updates need to be managed carefully and systems procedures need to be in place.

- Cyber-attacks are a real possibility, and can be unavoidable, so systems need to be designed in a way that prevents an attack on the entire autonomous fleet in one hit.
- As seen in broadcast TV services, autonomous vehicles could be designed with an A and B system, which would allow for reliability, redundancy, system control and monitoring functions to be designed in. Backup systems need to be automated in most cases – trains have two systems, and therefore need a fall-back system when things go wrong.
- Autonomous vehicles could have digital twins that can test software updates in a safe environment.
- The type of architecture, e.g. central or distributed, would act differently under an attack situation.

4. The approach to migration, and living with legacy systems



How can we build confidence in the transition to autonomy? When looking across maritime, aerospace, rail and road, the road sector probably has the least experience in the transition to autonomy, with rail having the most at a system level and aerospace at a functional level.

Migration is required at an operator level, i.e. the user needs to transition from using a vehicle that requires manual operation to one that is fully automatic. Migration also needs to be considered at a system level, where for a (probably significant) period of time there will be autonomous vehicles sharing the infrastructure with non-autonomous vehicles.

In the rail sector there are many examples where manually-driven trains share the same tracks as automatically-driven trains, however in all cases, unless in an emergency mode⁷, the train control system will ensure that a safe separation is achieved between the trains. This applies mostly on metros but has also been demonstrated on the 'core section' of Thameslink. For the introduction of driverless trains on the Victoria Line, TfL's transition plan was to initially de-rate the new trains with the software configured to deliver the same performance characteristics as the existing rolling stock. Similarly, as the signalling interlockings were

replaced, the new interlocking was initially designed to mimic what currently existed. Only when all the old stock had been replaced did the traction software get updated and the interlocking updated to deliver the improved performance.

The challenge with roads is again that the vehicles that are not autonomous are much more unpredictable than in any other sector as the operators are unskilled. Unlike airline pilots or train drivers, road users are not usually trained in simulators, so the transition from a car that is manually-driven to one that is fully autonomous (possibly even without a steering wheel) could be a 'culture shock' to say the least, and one that needs to be precisely managed.

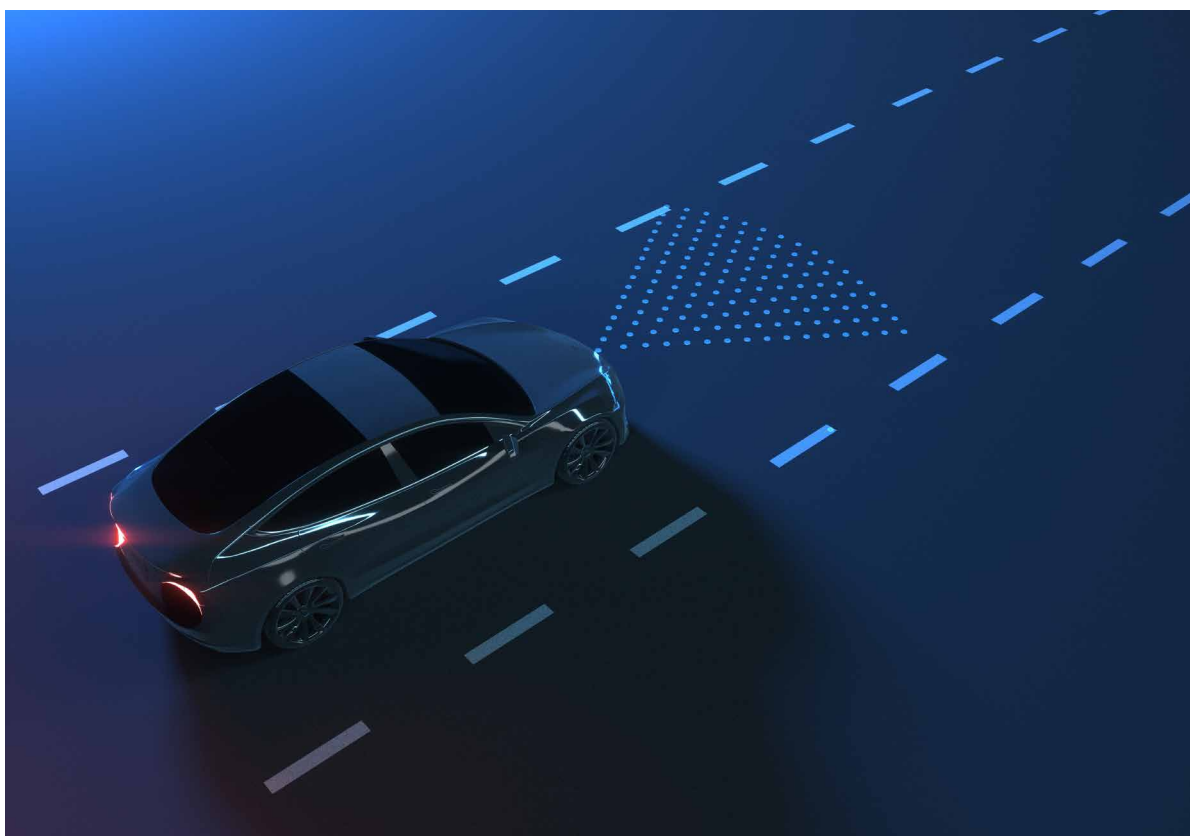
In a similar way, the safe transition from the road system we have today to a fully autonomous version will need very careful consideration. Experience to date has shown that even very limited numbers of autonomous vehicles mixed in with conventional traffic can lead to accidents, mostly because the autonomous vehicle did not behave as expected by the driver of the conventional vehicle.

⁷ In an emergency, with no train control system functioning, the maximum speed will be limited for example to 15kph, to reduce the consequences if the train-to-train separation is lost.

There are many possible options to consider. Below are a few examples, but the experience of the rail and aerospace sectors would be valuable in exploring this further.

- **Total segregation of autonomous and conventional vehicles** - This may be impractical because of the space required, but at the same time if more space was allocated to autonomous vehicles it may act as an incentive for the switch to AVs.
- **The characterisation of autonomous vehicles to behave like those driven manually** - This could be reversed when the population of conventional vehicles are in the minority.
- **Simulators for autonomous cars to help drivers of conventional vehicles become familiar with their characteristics** - This could be mandatory and involve degraded modes and emergency scenarios to give the user experience of what may happen.

Introducing a new aircraft, ship or train into controlled infrastructure is not easy, but the risks are very much reduced as there are skilled operators involved in the change. This is much more problematic with a transition from a conventional road system to an autonomous system when you have users that are unskilled. Options are available that include segregation and driver training, however the period of this transition should not be underestimated as it could be very prolonged. Additionally, the desire of people to 'drive' cars will never go away and even when the roads have a significant majority of vehicles that are autonomous, there is always the possibility that manually-driven cars will still need to use the system, although this may be only on specific routes and certain times of the day.





Problem Scenario – Rail

On metros it is an aim to reduce the headway to the shortest time possible. For example, the Victoria Line is currently achieving 34 trains per hour. This means that on the Victoria Line there are now more trains running than platforms available. Should there be a major issue, detraining is not as simple as each train getting to a station.

How to address it

- Fall-back procedures are essential and operational and investment decisions are needed to determine the level of redundant systems to provide baseline services.
- There might not be any staff on the train, so communications with staff would be critical.
- It will be essential to provide clear links between travellers and network operations managers, particularly in incident situations. Customer service will need to be a function of network management, not just something that is bolted on for information provision – although that will continue to be vitally important.
- Infrastructure inflexibility will restrict operational flexibility in incident management. In this instance, if there is a problem on a line that prevents passenger detraining, operational tools such as rerouting and line reversing would resolve incident situations.. However, whilst technology might provide the flexibility to make those operational decisions, additional points would be required to make it happen, with associated reliability challenges that make incidents more likely to occur. This means that increased operational flexibility needs to be accompanied by improved infrastructure, systems and equipment availability.
- Mobility as a Service (MaaS)⁸ is expected to become an essential element in the management of journeys in incident situations, but it will need to be flexible enough to cope with large numbers of people making 'abnormal' route and/or mode decisions with possible restrictions on infrastructure and/or services, with weather dependencies.

⁸ <https://www.theiet.org/impact-society/factfiles/transport-factfiles/could-mobility-as-a-service-solve-our-transport-problems/>

5. Ethics and the benefit to society



The introduction of autonomous systems raises important ethical issues including jobs, data privacy, safety and harm with their associated impact on society.

The more automation there is, the more human deskilling can be expected. Some driving and delivery jobs may be lost, for example, however the transition will not be immediate. Technology advancement has constantly changed work, and with the latest developments we can expect the creation of more skilled jobs. Those affected by the transition may need assistance to re-train or find alternative roles.

Automation goes hand-in-hand with the generation of data, which may be of a personal (time, location etc.) or commercial nature. It is important to ascertain who maintains the public stake in insights driven by the personal data⁹ collected by private firms. Cross-modal integration may magnify the data privacy issues.

During the transition to full automation there is likely to be a 'hand over to the human' phase where it becomes too difficult for an autonomous vehicle to cope. The 'trolley problem' has become a shorthand for ethical dilemmas about how to act in life and death situations. Automated vehicles, like other systems, will need to assess the risks of each manoeuvre against the risks of its alternatives. Typically, the problems involve course changes to avoid one group of people when that risks killing an innocent third person, or weighing one

life against another, such as a child against an older person. The questions raise issues about the concepts such as self-sacrifice, self-preservation, fault, the distinction between act and omission and the relative value of human life. Society accepts that drivers faced with life and death decisions act in the heat of the moment, without philosophical debate. However, people are more concerned about how programmers will weigh up the many competing interests, when they may be forced to directly or indirectly make similar decisions in advance.

The emergence of the term 'society in the loop' reflects the growing need for an implicit social contract between those developing and designing technology and those affected by it. Public acceptability of autonomous vehicles is likely to be affected by such considerations. There are particular concerns if decisions made by automated vehicles adversely affect a group of people on the basis of race, gender or other protected characteristics. Such bias is already against the law in various circumstances. The challenge is to provide sufficient training data across a wide enough pool of users to reduce the risk of biases in the way that a system detects and classifies things and learns behaviours. Questions that will need to be tackled include:

- Will autonomous vehicles differentially affect separate income groups in society?
- Will they increase or decrease inequality?
- How far will decision-making by automated vehicles be transparent and explainable?
- Will users be 'forced' to accept that the actions on an autonomous vehicle cannot be absolutely predicted?

Tackling autonomous systems from a cross-modal viewpoint is also an opportunity to share funding and speed up development. This can potentially be achieved through taking a common approach to developing regulation and standards, particularly for the high-risk and high-cost decision making architectures and software. This could include modelling tools, simulation and test facilities as well.

⁹ <https://ico.org.uk/for-organisations/guide-to-data-protection/guide-to-the-general-data-protection-regulation-gdpr/key-definitions/what-is-personal-data/>



Problem Scenario – Aerospace

Single-pilot operation of regional aircraft has become commonplace with routing and approach input by air traffic controllers and automatic landings mandated to increase capacity and reduce delays. The pilot is there only for public acceptability and to intervene in an emergency. On approach to Heathrow, in poor weather conditions, the aircraft suffers a major engine failure. How is the situation awareness and appropriate intervention of the pilot assured?

How to address it

- Pilot training in a simulator environment is critical to ensure the human interaction with the on-board autonomous systems is developed and practised.
- The key is the method for interaction between the human and the autonomous systems. Some level of engagement would be beneficial throughout the mission, as it would not be possible for the human to react adequately only in an emergency situation.
- The autonomous systems should help the human to avoid information overload, effectively performing a situational triage which would then inform decision making and prioritisation.
- The respective roles of autonomous systems and humans should be well considered to best utilise the different skillsets of autonomy versus humans.
- Human monitoring should be performed as well as system monitoring. This could enable a situation whereby, for example, if the human performance is compromised, the autonomous system could then take on greater functionality.

6. Conclusions and next steps

All transport modes are actively pursuing the benefits in cost, safety and flexibility from technical advances in computing and sensors that enable the development of semi- and fully-autonomous vehicles. These autonomous systems all share the same basic systems architecture and are dependent on the need for high integrity decision-making software. There is, therefore, the potential to share knowledge and costs as well as speed up development by cooperation across the sectors. There is also advantage in taking a common approach to safety standards to address public acceptance issues.



Although the IET and its members have the knowledge, expertise and understanding to engage in and lead further debate around this important societal topic, they cannot facilitate the cross-sector collaboration required alone. This should be driven by government with the support of industry. We recommend that government progresses the following three actions:

1. Work with professional bodies such as the IET to raise awareness of the challenges and opportunities for cross-modal learning within industry.
2. Form a cross-government and cross-engineering professional body working group to develop the opportunities for cross-sector collaboration outlined in this report.
3. Facilitate cross-sector collaboration and knowledge transfer through the implementation of an Autonomy Accelerator. The centre would be responsible for:
 - a. Establishing a workforce with the digital skills required for autonomy through training, retraining and cross-sector secondments.
 - b. Developing a standardised approach, regulations, tools and facilities, particularly in the development of decision-making systems.

- c. Sharing experience of achieving and managing safe migration from legacy to autonomous systems and the continuing integration with legacy systems.
- d. Supporting government policy development and funding cross-sector research, development and demonstration (RD&D) programmes.

The IET believes the above steps will allow the transport sectors to learn from the experiences of other sectors and avoid any mistakes that have been made in the past. This will reduce the steepness of the learning curve, accelerate the time to market and decrease the risk of accidents. The IET would be very keen to support government with this.

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