The journey to an autonomous transport system: identifying challenges across multiple modes

Summary of a roundtable discussion
December 2020

As part of the National Engineering Policy Centre’s (NEPC) project on Safety and Ethics of Autonomous Systems, we brought together individuals from across a range of different transport modes and disciplines to discuss and debate the latest state of play in autonomy and the issues arising. This ‘transport deep dive’ summarises the range and diversity of views and discussions captured at this roundtable and sets out some important questions for consideration.

The issues we uncovered are complex and many questions still remain. By publishing this paper now we hope to move this debate forward by stimulating thinking about how these challenges can be tackled. We think it is important to highlight the cross-cutting challenges that exist to decision-makers and regulators that can open up opportunities for further cross-modal collaboration.

In parallel, this paper is also aimed at encouraging engineering developers to share insights and identify co-benefits across modes. Transport is the focus of our first sector deep dive, with further deep dives in health and care and social media to follow. Our aim is to build our evidence base to develop a wider understanding across different sectors, so that we can make recommendations to support the safe and ethical development and deployment of autonomous systems across the UK.

Executive Summary

The Safety and ethics of autonomous systems project overview outlined a need for further sectoral exploration of the role autonomous systems could play. This output is the first of a series of sector specific deep dives.

To investigate the opportunities and challenges to develop an autonomous transport network, the National Engineering Policy Centre (NEPC) held a roundtable. This looked at modes including road, air, sea and rail and brought together a range of expert stakeholders from technical, legal and policy perspectives.

Autonomous systems can create safer, more efficient and lower carbon transportation systems. Realising these benefits is dependent on how the future transport system is envisioned, engineered, and implemented. Numerous challenges need to be overcome before widespread deployment is possible.

This summary sets out the current technological state of the art, domain challenges such as decision-making time and software ownership, and cross-cutting challenges such as safety assurance, ethical considerations and public perception. It also highlights several enabling factors: skills, infrastructure, legislation, interoperability, and culture change, (Figure 1).
The journey to an autonomous transport system: identifying challenges across multiple transport modes

The expectations from an autonomous transport system are yet to be defined in terms of safety and service provision. Public acceptability across transport modes will have different challenges depending on how the public interacts with it, the complexity of environment and degree of industry unionisation.

Developing technologies and services that are trustworthy, ethical and inclusive will require extensive consultation, multidisciplinary collaboration and culture change. Whether societal expectations should be a consideration for systems decision-making processes for autonomous transport has to be decided.

Common frameworks will be required to support engineers to make ethical decisions. As driverless transport evolves the future technical and ethical competencies need to be defined to equip engineers with the skills required to be responsible professionals.

Technical challenges focus on the need for new validation and verification techniques alongside simulation and real world trials to assure safe and timely decision-making. This can further be supported by secure connective infrastructure.

Real-world trials also help identify gaps in UK and international regulation, legislation and insurance models. Collaborative and agile development of the regulatory environment will help these to be future proofed. Regulators need to be equipped with the complex technical skills to challenge and assess compliance.

The COVID-19 pandemic has highlighted new needs for these technologies that were not previously anticipated. This has accelerated innovation in autonomous systems for the delivery of goods. Deploying these technologies will inevitably highlight new challenges and ways to overcome them. Depending on their success, this may influence public trust for autonomous systems in transport so, despite the need, these innovations should be deployed in a considered manner.

Introduction

To build on a cross-sectoral understanding of some of the challenges associated with autonomous systems, a series of sector deep dives set out to explore what is unique about how autonomous systems are developing in each sector: the specific challenges to safe and ethical deployment; and identification of opportunities and emerging good practice.

On 15 January, the NEPC held a roundtable discussion on the development of autonomous systems in transport. This looked across different transport modes including road, air, sea, and rail, bringing together experts with technical, legal and policy perspectives.

This paper explores several questions including:

- how do the modes compare?
- accelerating innovation during the COVID-19 pandemic
- how can safety be assured?
- how safe is safe enough?
- what are the ethical considerations?
- what are the enabling factors?
- what might influence public perceptions?

Developing and deploying autonomous systems for transportation is challenging. There is complexity associated with the physical and social operating environment, the existing supply chain, and the requirement for real-time decision-making.

There is significant automation of many functions across the current transport system, but this technology is deterministic, meaning that the same inputs always result in the same outputs. This includes cruise control in vehicles, automatic door closing on trains and fly-by-wire software in aeroplanes. Increasing autonomy poses new challenges as these systems are adaptive and able to make decisions based on the specific circumstances; this means that the same inputs will not always result in the same outputs.

Maximising the benefits of these advancing technologies will require full integration across the different modes of the transport system and a careful and considered approach to deployment.

Autonomous systems can be a cross-cutting technology but there is limited knowledge sharing across the modes of transport. While the technological state of the art and drivers for innovation vary there is an opportunity for cross-modal learning for engineers, regulators and legislators to ensure safe and ethical development and deployment of autonomous systems.
The journey to an autonomous transport system: identifying challenges across multiple transport modes

How do the modes compare?

**Presence of automation**
- **Road:** Modern cars already come with different degrees of automated functions from simple cruise control to more advanced lane changing and self-parking capabilities.
- **Air:** Self-driving cars are being developed by classic automotive original equipment manufacturers (OEMs) and university spin-offs are developing autonomous software. In the UK, the enabling software is advancing fast.
- **Sea:** UAM requires value chain transformation to provide the new aircraft designs, flight operations for vertical take-off and landing (VTOL) planes, ground infrastructure, and uncrewed traffic management systems. Elements of this system have been tested in isolation such as VTOL autonomous passenger demonstrators, but there is much further development needed. It is anticipated that many of these challenges can be overcome with the technology development in delivery drones.
- **Rail:** For Crossrail, a hybrid service of heavy rail and mass transit, the aim is for the train to turn around autonomously at the end of the track while the driver is walking to the other end of the platform. This reduces the turnaround time resulting from engaging a second engine.

**Drivers of progress**
- **Road:** Potential safety improvements and a supportive policy environment have resulted in a sense of inevitability about the arrival of autonomous vehicles.
- **Air:** Autonomous flight requires adjustments to many parts of the system grouped together as urban air mobility (UAM).
- **Sea:** Advancements in UAM are driven by increasing urbanisation, technological advancement and pilot shortages.
- **Rail:** Rail automation has focused on reducing operating costs, increased service reliability and throughput to allow for greater capacity.

**Where are developments being made?**
- **Road:** UAM requires value chain transformation to provide the new aircraft designs, flight operations for vertical take-off and landing (VTOL) planes, ground infrastructure, and uncrewed traffic management systems. Elements of this system have been tested in isolation such as VTOL autonomous passenger demonstrators, but there is much further development needed. It is anticipated that many of these challenges can be overcome with the technology development in delivery drones. Some operational risks can be mitigated by removing onboard crew. As such, some sectors of the maritime industry are adopting the use of uncrewed vessels. These are equipped with the ability to carry out remote control interventions, combined with the use of some autonomous systems as a more flexible, cost-effective and safer alternative for gathering critical data about the ocean. Autonomous underwater vehicles are already being used for deep-sea exploration and pipeline inspection.

**Current state of the art**
- **Road:** Cars operating autonomously with oversight from safety drivers are being trialled in cities across the UK today. In January 2020, Airbus reported its first automated vision-based take-off 9 to take this to the next stage, industry is currently developing strategies for the future of UAM. In Singapore, an Airbus autonomous drone have been trialled over densely populated areas delivering goods from ship to shore in defined aerial corridors. However, to become widely operational, further work is required to deploy operations beyond visual line of sight in unsegregated airspace.
- **Air:** In Singapore, 25kg autonomous drones have been tested in defined aerial corridors. In January 2020, Airbus reported its first automated vision-based take-off to take this to the next stage, industry is currently developing strategies for the future of UAM.

**Example of mode specific challenges?**
- **Road:** The complexity of the surrounding environment will influence the complexity of the system. On the road there are many interacting players and the challenge for the self-driving car is to anticipate their behaviours (Figure 3). To characterise the situation and assess the potential risk, a large volume of data must be processed. There is minimal time available for decision-making and retrospection.
- **Air:** Some operational risks can be mitigated by removing onboard crew. As such, some sectors of the maritime industry are adopting the use of uncrewed vessels.
- **Sea:** Autonomous underwater vehicles are already being used for deep-sea exploration and pipeline inspection.
- **Rail:** Rail automation has focused on reducing operating costs, increased service reliability and throughput to allow for greater capacity.

**Decision-making time**
- **Road:** Decision-making time is typically responsible for the self-driving car. To make a change to the test fleet.

**Demonstrator permissions**
- **Road:** NASA has delivered early operational demonstrations. To be equipped with the ability to carry out remote control interventions, combined with the use of some autonomous systems as a more flexible, cost-effective and safer alternative for gathering critical data about the ocean.

**Connectivity**
- **Road:** Connectivity is a challenge that needs to be overcome to ensure efficient and safe international operations. Multiple wireless systems are needed for resilience and global communications networks could provide important enabling infrastructure.

**Software ownership**
- **Road:** The software ownership can affect the pace of change. In current autonomous vehicle demonstrators, it can take just six hours to make a change to the software and apply this to the test fleet. By comparison, the outsourcing process in rail is reported to result in an eight-week software development cycle with a further 17 weeks to ensure the functional safety of the software. For public procurement, the ownership of the software algorithms needs to be considered carefully.
The UK lockdown has highlighted the important role that autonomous systems could play. Testing and feasibility studies are being funded to speed up innovation to support future deployment.

In the UK, UK Research and Innovation (UKRI) has funded developers with autonomous systems that can support delivery and logistics, monitoring, and disinfection (Table 1). These aren’t transport applications specifically but demonstrate how this technology can create opportunities to highlight public benefit and build trust, paving the way for future advances in transport applications.

For more advanced innovations, the increased need for goods to be delivered has seen a surge in demand for the services of pavement delivery robots, such as Starship Technologies operating in Milton Keynes. Similarly in the US, Nuro, a self-driving delivery van, was recently granted a fixed-term regulatory exemption enabling it to operate on the roads autonomously without features that allow a driver take control.

Table 1. UKRI projects funding the development of autonomous systems

<table>
<thead>
<tr>
<th>Application</th>
<th>Organisation</th>
<th>Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delivery and logistics</td>
<td>Academy of Robotics</td>
<td>Semi-autonomous last-mile delivery in which medicines can be delivered from pharmacies to care homes without human contact.</td>
</tr>
<tr>
<td></td>
<td>Toshiba Research Europe</td>
<td>Fleet of logistics robots capable of autonomously coordinating delivery of vital supplies in ad-hoc arenas.</td>
</tr>
<tr>
<td></td>
<td>Skyfarer Ltd</td>
<td>Feasibility study for a platform that allows any organisation to access an ecosystem of drones, to then be used to distribute medication, blood, test kits, food and digital devices.</td>
</tr>
<tr>
<td></td>
<td>Hybrid Drones Ltd</td>
<td>Aiming to autonomously carry a maximum payload of 100kg, over a distance of 10km, within 10 minutes.</td>
</tr>
<tr>
<td>Crowd monitoring</td>
<td>Level five supplies Ltd</td>
<td>Unmanned aerial vehicle (UAV) crowd-monitoring tool measures the location of people in open spaces, covering up to 30,000 sq m (line of sight) per system.</td>
</tr>
<tr>
<td>Disinfection</td>
<td>Unmanned life</td>
<td>Fleet of autonomous drones and robots to disinfect large spaces, both indoors and outdoors.</td>
</tr>
</tbody>
</table>

Despite recent progress across the modes there are many common challenges, including assuring safety and trustworthiness, managing complexity, and oversight.

How can safety be assured?

As different components of autonomous transport software and hardware are integrated, dependencies will be created between these elements. This means that testing components in isolation is not representative of the system. Instead autonomous systems must be tested together and validated as a whole, through a variety of mechanisms.

Success is dependent on correct characterisation of system behaviour in different scenarios. Validation of these requirements is a real challenge but it is critical to ensure confidence that the right behaviours have been identified for the system at the point where an action is committed.

Software has historically been assured with formal methods, mathematical proofs that the system behaves as designed. However, as the code is continuously being updated and the complexity of the code grows to millions of lines, the applicability of traditional formal methods is limited. Other methods of developing self-driving software rely on end-to-end machine learning, for which formal methods cannot currently be applied. Engineers have a vital role in developing the new methods of verification that are required to replace formal methods.

For self-driving cars there has been a recognition that classical, functional safety assessments do not apply for autonomous systems, as failure mechanisms are more complex than electronic system malfunctions. This has resulted in a new thinking around safety for example, safety of the intended functionality philosophy (SOTIF) and responsibility-sensitive safety methodology (RSS).

SOTIF aims to deal with uncertainty by defining standards that demonstrate that the system would never get itself into an accident without an external actor making a significant error.

RSS is a formal, mathematical model to measure a vehicle’s behaviour in terms of responsibility and caution. It assesses performance for safe distancing, lane changing, giving way, increased caution for limited visibility and the response to a dangerous scenario.

In the UK, the approach to assuring safety and security will be supported by the development of CAV PASS, a system to support trials without a human and novel vehicle types. Similar techniques may be applicable to other modes.

Cross-cutting themes

Testing in real-world scenarios is a vital component (Figure 2). It provides an understanding of the technical performance, deployment on roads, rails, airways or

Figure 2. Oxbotica software characterising the environment
The journey to an autonomous transport system: identifying challenges across multiple transport modes

international waters and helps to identify the gaps in existing regulation legislation and insurance. In vehicles, this has also highlighted inconsistencies between vehicle decision-making and human expectations. It is also important that transport autonomous systems can operate safely and effectively in mixed environments alongside humans.

There is an additional role for simulation for which artificial intelligence is being used to create a wide range of scenarios for systems to be tested in. This allows combinations of weathers, environments and reflections to be varied to create new scenarios that have not been experienced before. Opportunities should be taken to embed the experiences and expectations of the safety operators within the testing to test the performance. These approaches enable testing of the software in new scenarios that are comparable to the real world.

A safe by design philosophy needs to be embedded for autonomous systems. This is already common practice in existing passenger planes, other modes are also building for redundancy to ensure that if elements should fail or be physically disrupted there will be alternative routes to maintain the necessary functionality.

When these systems operate even more autonomously, making more decisions without oversight, existing safety cases will only provide assurance to a certain point. A decision must be actively made to pursue this next level of autonomy informed by the public, industry and policymakers. If this is decided, new methods will be required to cope with the step-change of fully removing the human from the loop.

How safe is safe enough?

The code of practice for autonomous vehicles outlines the safety expectations but industry is going beyond compliance, aspiring to higher safety standards. However, the details of what the market will expect for road vehicles are yet to be defined.

For aerospace, these initial safety expectations have not been set out, instead industry and regulators are working together to identify an approach. Across the modes, collaborative deliberation is required to define safety standards, and stakeholders who will be directly and indirectly affected should be consulted.

As technology is relied upon further there is a question as to whether the safety expectations should be the same across modes. The risk is typically framed in micromorts: on the road the acceptable risk is pitched at $10^{-7}$ based on the idea that the addition of vehicles should not affect the mortality rate of a typical healthy youth. However, providing proof of this is difficult prior to wide scale use.

While there are challenges to assuring safety there are areas where autonomous systems could provide transformative safety improvements. A report by TRL predicted that if 8% to 19% of the total car fleet was autonomous by 2040, up to 650 fatal and serious injury collisions could be prevented annually. Another industry with opportunities for safety improvements is fishing, which has reported 79 fatalities and 572 injuries on UK fishing vessels between 2008 and 2018.
What are the ethical considerations?

Many of the ethical discussions held in the public domain focus on the trolley problem (Figure 4). This can help to engage the population in the idea of delegating a decision to a machine and to discuss the burden of intervention. However, the specific problem posed is a no-win scenario and an ability to accurately predict has been assumed.

For each decision an autonomous transport system must understand where it is, what’s around it and what that might do, and identify the least harmful action in the time available. The available time to decide varies depending on the mode of transport.

For the programmer many of the ethical issues are safety issues and the safest action isn’t always the most socially acceptable. There is a question whether the soft rules of the road, which are embedded with societal expectations, should be a layer on the systems decision-making process. In vehicles, unexpected behaviours can have knock-on effects for other road users, which is also likely to apply to the maritime conventions. This asks the question whether it is ethical for a self-driving car to reduce the risk of knock-on consequences rather than being perceived as ‘unsafe’ when taking the statistically safest action. Just as drivers are not homogenous, one safety driver may not flag the same risk as another, so rationalising these views into a definitive action is a challenge. There may be a need for frameworks that support engineers to make these ethically charged decisions. To what extent can considerations of ethical by design be embedded in the safety assurance process to ensure compliance?

There are further wider ethical considerations in how these systems are deployed, with questions such as:

- The balance between investment in mass transit systems or individual mobility.
- Autonomous systems present significant potential for lower-carbon transport but this will depend on how they are operationalised, how can the environmental impact have a similar weighting to safety?
- Are the business models driving these technologies fair and sustainable?
- Who will own the data that is collected and who profits from the understanding of passenger preferences?
- The impact on certain individuals and social groups also needs to be considered. For example, if there is an aversion to full autonomy on ships, a halfway step may be to include one or two individuals onboard in a form of human-autonomy teaming. Such isolation can have major implications for an individual’s mental health and these harms need to be considered alongside physical safety.

![Figure 4. The Trolley problem](image)

The trolley problem is an ethical thought experiment that presents no-win moral dilemmas that ask whether you would take action in order to sacrifice one person to save a larger number.

What are the enabling factors?

Infrastructure

Across the transport modes, benefits would be enabled faster with the right infrastructure provision. Connectivity is one example, as smart environments can increase the understanding a system has of its environment. If modelling the environment was an option so that different actors could communicate, uncertainty would be diminished, reducing the complexity of computational decisions made by individual autonomous systems.

In maritime, port infrastructure is important. Australia has two ports, which operate autonomously and have showcased many benefits across safety, productivity and efficiency. Investment in public infrastructure needs to deliver benefit for society as well as industry as they bear the cost. For the Finnish demonstrator, new land-based infrastructure was required involving creation of a new safety case, which came at significant expense.

To scale, efficient drone delivery of goods from ship to shore will require specific infrastructure. For its Singapore trial, Airbus installed several parcel stations to shore will require specific infrastructure. For its Singapore trial, Airbus installed several parcel stations across the city for the drone to land and manage the parcels.

Integration with legacy systems is a known challenge for autonomous systems. Both air and rail must integrate with existing air traffic management and automatic train supervision systems to manage the throughput safely and effectively. These systems will be improved by better use of data and real-time monitoring and prediction.

Skills

Across the modes, there are skills gaps for technology, regulation and legislation. There may be a role for a competency framework that could apply across the different transport domains to identify the future skills needs. However, there are already challenges to identifying current competencies for software engineering. This should be accompanied by a training needs assessment that considers both hard and soft skills.

The speed of technological progress makes it difficult to ensure that regulators have enough understanding to be able to competently assess compliance. As with previous technology evolutions, competing with industry for a limited pool of skilled professionals will affect regulatory capacity.

Legislation

The pace of change is likely to be affected by whether the operations are national or international. Global regulation and legislation are necessary components to enable autonomy across modes, especially for maritime and aerospace industries. The International Maritime
The journey to an autonomous transport system: identifying challenges across multiple transport modes

Interoperability

Interoperability between different modes and systems is vital to maximise the benefits. Common standards between modes could enable this integration across the transport sector. Facilitating interoperability becomes difficult in the international context, as the degree of acceptability will vary from country to country.

A disconnect exists between the different modes of transport, which reflects historical silos within government. The future mobility industrial strategy grand challenge has a role to enable this coordination. It is also important to ensure alignment with artificial intelligence policies emerging from department for digital, culture, media, and sport or recommendations from the centre for data ethics and innovation to create a holistic regulatory environment.

What might influence public perceptions?

One of the biggest obstacles to overcome with autonomy across transport modes is public acceptance. The press has a significant role to play in how this technology is presented and the job loss narratives can create fear and apprehension.

The government’s narrative also influences public perception. Government aspirations for uk leadership in autonomous transport may be associated with a relaxed regulatory approach.

There are further specific challenges depending on the mode (figure 6).

Figure 6. Considerations that may influence stakeholder perceptions in different modes.

Legend

Passengers taking a flight are often unaware it will be largely controlled by a machine. The idea of there being no pilot can make people very uncomfortable.22

Many people consider themselves an expert when it comes to driving which can make them more critical of self-driving vehicles.

Passengers prefer a smooth driving experience but the role of change in acceleration also influences the behaviours of the pedestrian and other road users.

Trade unions play an influential role in the attempts to increase automation of train transport.

There are safety concerns about risk increased suicide attempts with driverless trains.

Autonomous shipping would mean a fundamental change in what it means to be a seafarer. This could have a positive impact as seafarers can be particularly susceptible to mental health issues. In the short term, mental health problems could rise if increasing automation on the route to autonomy results crew sizes being reduced.
The journey to an autonomous transport system: identifying challenges across multiple transport modes

Conclusion

The multimodal perspectives brought together through this transport deep dive roundtable highlights the need for a much more joined up and collaborative approach to autonomous systems development and deployment across transport domains. There are co-benefits that can be amplified through the design and development of an integrated, interoperable transport and infrastructure system. Making sure that end-users and those impacted or displaced by the uptake of this technology are involved in the development and deployment will ensure that benefits are more equitably distributed.

There are still many challenges which remain, spanning technical, ethical, regulatory, professional, public and oversight areas of the framework. In certain modes, research and innovation funding and support is helping to address these challenges. For example:

- research funding through the Trustworthy Autonomous Systems Strategic Priorities Fund will start to answer the technical verification and validation questions
- technology demonstrators in Future Flight and Self-Driving Vehicles Challenges (supported by the Industrial Strategy Challenge Fund) and the Connected Places Catapult are laying the groundwork for the necessary regulatory, ethical and logistical conditions
- regulatory collaboration is being enabled through mechanisms like the Regulators Pioneer Fund, which supports the Maritime and Coastal Agency, and the collaborative programmes Centre for Connected and Autonomous Vehicles (CCAV). These initiatives are welcome and are step in the right direction. However, there is still more to do, and still areas where more targeted support would be beneficial, including:
  - foster cross collaboration between modes and disciplines to enable experience sharing and learning from a range of perspectives and to make collective decisions that merit public support and ensure alignment across infrastructure, levelling up and decarbonisation agendas
  - develop a training pipeline that creates, reskills and upskills the engineering profession to develop, deploy and maintain these autonomous transport solutions throughout their lifetimes while simultaneously evolving and maintaining technical and ethical competencies
  - establish the oversight mechanisms to attribute responsibility and improve transparency and information sharing across the whole transport system.

Next steps

This is the first of a series of sectoral deep dives, further evidence gathering is planned for health and care and social media. By exploring the evidence base across three very different sectors, we aim to better understand the technology context behind each one, identify common challenges, and make recommendations that cut across sectors to support safe and ethical development and deployment of autonomous systems.

The NEPC will continue to publish the proceedings and insights as they emerge to feed into the debate. If you are interested in learning more please contact NEPC@raeng.org.uk or visit our webpage: www.raeng.org.uk/policy/safety-and-ethics-of-autonomous-systems

References

1 Royal Academy of Engineering (2020) Safety and ethics of autonomous system project overview
2 Ibid
3 Swire Seabed (2019) Swire Seabed completes unmaned subsea pipeline inspection for Equinor in the North Sea
4 Department of Business, Energy and Industrial Strategy Press Release (2018) From science fiction to reality: People in London and Edinburgh set to be the first to trial self-driving vehicle services
5 Human drive (2020) Nissan Leaf completes the UK’s longest and most complex autonomous journey
6 The Automated and Electric Vehicles Act 2018
7 Centre for Connected and Autonomous Vehicles (2019) Code of Practice: Automated vehicle trialling
8 Airbus (2020) Airbus demonstrates first fully automatic vision-based take-off
9 Airbus (2019) Airbus skysways drone trials world’s first shore-to-ship deliveries
10 Operation Zenith
11 SEA-KIT (2019) SEA-KIT docks in Belgium to complete first ever international commercial uncrewed transit
12 Rolls-Royce (2018) Rolls-Royce and Finferries demonstrate world’s first Fully Autonomous Ferry
13 Thales (2019) The path to an autonomous train
14 Covid-19 research and innovation supported by UKRI
15 Robots deliver food in Milton Keynes under coronavirus lockdown
16 Nuro, NHTSA, and the New Autonomous Vehicle Exemption Rules
17 ISO/PAS 21448:2019 – Road vehicles – Safety of the intended functionality
18 Mobilityx - Implementing the RSS Model on NHTSA Pre-Crash Scenarios
19 Department for Transport (2019) New system to ensure safety of self-driving vehicles ahead of their sale
The Royal Academy of Engineering is harnessing the power of engineering to build a sustainable society and an inclusive economy that works for everyone.

In collaboration with our Fellows and partners, we’re growing talent and developing skills for the future, driving innovation and building global partnerships, and influencing policy and engaging the public.

Together we’re working to tackle the greatest challenges of our age.

What we do

TALENT & DIVERSITY
We’re growing talent by training, supporting, mentoring and funding the most talented and creative researchers, innovators and leaders from across the engineering profession.

We’re developing skills for the future by identifying the challenges of an ever-changing world and developing the skills and approaches we need to build a resilient and diverse engineering profession.

INNOVATION
We’re driving innovation by investing in some of the country’s most creative and exciting engineering ideas and businesses.

We’re building global partnerships that bring the world’s best engineers from industry, entrepreneurship and academia together to collaborate on creative innovations that address the greatest global challenges of our age.

POLICY & ENGAGEMENT
We’re influencing policy through the National Engineering Policy Centre – providing independent expert support to policymakers on issues of importance.

We’re engaging the public by opening their eyes to the wonders of engineering and inspiring young people to become the next generation of engineers.

National Engineering Policy Centre
We are a unified voice for 43 professional engineering organisations, representing 450,000 engineers, a partnership led by the Royal Academy of Engineering.

We give policymakers a single route to advice from across the engineering profession. We inform and respond to policy issues of national importance, for the benefit of society.

Royal Academy of Engineering
Prince Philip House
3 Carlton House Terrace
London SW1Y 5DG
Tel 020 7766 0600
www.raeng.org.uk
@RAEngNews

Registered charity number 293074

Annex A:

Framework summarising the cross-sectoral challenges faced by autonomous systems

- Technical
  - Challenges: Validation & verification of current safety assurance models, to provide certainty in a system’s capabilities. Development of new methods alongside real world trials and simulations.

- Professional responsibility
  - Challenges: Evolution of current regulation as best practice emerges e.g. codes of practice to encourage responsible behaviours and culture change. Decisions about the role of non-regulatory mechanisms.

- Autonomous systems
  - Challenges: Societal and cultural structures can act as barrier. Demands placed on surrounding environment due to transformative technologies. Greater collaboration to build trust between individuals and the service provider.

- Oversight
  - Challenges: Greater oversight as deployment in increasingly large and more complex environments raises liability and authority issues. Governance in place to judge whether/s if benefits should be realised despite uncertainty and risk.

- Regulation
  - Challenges: Regulation which can stimulate innovation, which is outcome focussed, globally relevant, informed by stakeholders and supportive of innovators. A leading, agile and responsive UK regulatory system that connects across the many silos.

- Public acceptance
  - Challenges: Societal and cultural structures can act as barrier. Demands placed on surrounding environment due to transformative technologies. Greater collaboration to build trust between individuals and the service provider.

- Ethics
  - Challenges: Lack of human oversight and transparency in complex environments and risk of harm through system design and deployment. Collective, reflective decision making to resolve moral uncertainty.

- Professional responsibility
  - Challenges: Evolution of current regulation as best practice emerges e.g. codes of practice to encourage responsible behaviours and culture change. Decisions about the role of non-regulatory mechanisms.

- Autonomous systems
  - Challenges: Societal and cultural structures can act as barrier. Demands placed on surrounding environment due to transformative technologies. Greater collaboration to build trust between individuals and the service provider.

- Oversight
  - Challenges: Greater oversight as deployment in increasingly large and more complex environments raises liability and authority issues. Governance in place to judge whether/s if benefits should be realised despite uncertainty and risk.

- Regulation
  - Challenges: Regulation which can stimulate innovation, which is outcome focussed, globally relevant, informed by stakeholders and supportive of innovators. A leading, agile and responsive UK regulatory system that connects across the many silos.

- Public acceptance
  - Challenges: Societal and cultural structures can act as barrier. Demands placed on surrounding environment due to transformative technologies. Greater collaboration to build trust between individuals and the service provider.

- Ethics
  - Challenges: Lack of human oversight and transparency in complex environments and risk of harm through system design and deployment. Collective, reflective decision making to resolve moral uncertainty.

- Professional responsibility
  - Challenges: Evolution of current regulation as best practice emerges e.g. codes of practice to encourage responsible behaviours and culture change. Decisions about the role of non-regulatory mechanisms.

- Autonomous systems
  - Challenges: Societal and cultural structures can act as barrier. Demands placed on surrounding environment due to transformative technologies. Greater collaboration to build trust between individuals and the service provider.

- Oversight
  - Challenges: Greater oversight as deployment in increasingly large and more complex environments raises liability and authority issues. Governance in place to judge whether/s if benefits should be realised despite uncertainty and risk.

- Regulation
  - Challenges: Regulation which can stimulate innovation, which is outcome focussed, globally relevant, informed by stakeholders and supportive of innovators. A leading, agile and responsive UK regulatory system that connects across the many silos.

- Public acceptance
  - Challenges: Societal and cultural structures can act as barrier. Demands placed on surrounding environment due to transformative technologies. Greater collaboration to build trust between individuals and the service provider.

- Ethics
  - Challenges: Lack of human oversight and transparency in complex environments and risk of harm through system design and deployment. Collective, reflective decision making to resolve moral uncertainty.

- Professional responsibility
  - Challenges: Evolution of current regulation as best practice emerges e.g. codes of practice to encourage responsible behaviours and culture change. Decisions about the role of non-regulatory mechanisms.

- Autonomous systems
  - Challenges: Societal and cultural structures can act as barrier. Demands placed on surrounding environment due to transformative technologies. Greater collaboration to build trust between individuals and the service provider.

- Oversight
  - Challenges: Greater oversight as deployment in increasingly large and more complex environments raises liability and authority issues. Governance in place to judge whether/s if benefits should be realised despite uncertainty and risk.

- Regulation
  - Challenges: Regulation which can stimulate innovation, which is outcome focussed, globally relevant, informed by stakeholders and supportive of innovators. A leading, agile and responsive UK regulatory system that connects across the many silos.

- Public acceptance
  - Challenges: Societal and cultural structures can act as barrier. Demands placed on surrounding environment due to transformative technologies. Greater collaboration to build trust between individuals and the service provider.

- Ethics
  - Challenges: Lack of human oversight and transparency in complex environments and risk of harm through system design and deployment. Collective, reflective decision making to resolve moral uncertainty.

- Professional responsibility
  - Challenges: Evolution of current regulation as best practice emerges e.g. codes of practice to encourage responsible behaviours and culture change. Decisions about the role of non-regulatory mechanisms.

- Autonomous systems
  - Challenges: Societal and cultural structures can act as barrier. Demands placed on surrounding environment due to transformative technologies. Greater collaboration to build trust between individuals and the service provider.

- Oversight
  - Challenges: Greater oversight as deployment in increasingly large and more complex environments raises liability and authority issues. Governance in place to judge whether/s if benefits should be realised despite uncertainty and risk.

- Regulation
  - Challenges: Regulation which can stimulate innovation, which is outcome focussed, globally relevant, informed by stakeholders and supportive of innovators. A leading, agile and responsive UK regulatory system that connects across the many silos.

- Public acceptance
  - Challenges: Societal and cultural structures can act as barrier. Demands placed on surrounding environment due to transformative technologies. Greater collaboration to build trust between individuals and the service provider.

- Ethics
  - Challenges: Lack of human oversight and transparency in complex environments and risk of harm through system design and deployment. Collective, reflective decision making to resolve moral uncertainty.

- Professional responsibility
  - Challenges: Evolution of current regulation as best practice emerges e.g. codes of practice to encourage responsible behaviours and culture change. Decisions about the role of non-regulatory mechanisms.

- Autonomous systems
  - Challenges: Societal and cultural structures can act as barrier. Demands placed on surrounding environment due to transformative technologies. Greater collaboration to build trust between individuals and the service provider.

- Oversight
  - Challenges: Greater oversight as deployment in increasingly large and more complex environments raises liability and authority issues. Governance in place to judge whether/s if benefits should be realised despite uncertainty and risk.

- Regulation
  - Challenges: Regulation which can stimulate innovation, which is outcome focussed, globally relevant, informed by stakeholders and supportive of innovators. A leading, agile and responsive UK regulatory system that connects across the many silos.

- Public acceptance
  - Challenges: Societal and cultural structures can act as barrier. Demands placed on surrounding environment due to transformative technologies. Greater collaboration to build trust between individuals and the service provider.

- Ethics
  - Challenges: Lack of human oversight and transparency in complex environments and risk of harm through system design and deployment. Collective, reflective decision making to resolve moral uncertainty.

- Professional responsibility
  - Challenges: Evolution of current regulation as best practice emerges e.g. codes of practice to encourage responsible behaviours and culture change. Decisions about the role of non-regulatory mechanisms.

- Autonomous systems
  - Challenges: Societal and cultural structures can act as barrier. Demands placed on surrounding environment due to transformative technologies. Greater collaboration to build trust between individuals and the service provider.

- Oversight
  - Challenges: Greater oversight as deployment in increasingly large and more complex environments raises liability and authority issues. Governance in place to judge whether/s if benefits should be realised despite uncertainty and risk.

- Regulation
  - Challenges: Regulation which can stimulate innovation, which is outcome focussed, globally relevant, informed by stakeholders and supportive of innovators. A leading, agile and responsive UK regulatory system that connects across the many silos.

- Public acceptance
  - Challenges: Societal and cultural structures can act as barrier. Demands placed on surrounding environment due to transformative technologies. Greater collaboration to build trust between individuals and the service provider.

- Ethics
  - Challenges: Lack of human oversight and transparency in complex environments and risk of harm through system design and deployment. Collective, reflective decision making to resolve moral uncertainty.

- Professional responsibility
  - Challenges: Evolution of current regulation as best practice emerges e.g. codes of practice to encourage responsible behaviours and culture change. Decisions about the role of non-regulatory mechanisms.

- Autonomous systems
  - Challenges: Societal and cultural structures can act as barrier. Demands placed on surrounding environment due to transformative technologies. Greater collaboration to build trust between individuals and the service provider.

- Oversight
  - Challenges: Greater oversight as deployment in increasingly large and more complex environments raises liability and authority issues. Governance in place to judge whether/s if benefits should be realised despite uncertainty and risk.

- Regulation
  - Challenges: Regulation which can stimulate innovation, which is outcome focussed, globally relevant, informed by stakeholders and supportive of innovators. A leading, agile and responsive UK regulatory system that connects across the many silos.

- Public acceptance
  - Challenges: Societal and cultural structures can act as barrier. Demands placed on surrounding environment due to transformative technologies. Greater collaboration to build trust between individuals and the service provider.