

Automated Vehicles

Cross-modal learning in autonomy



Foreword

I am delighted to receive this report on cross-modal learning from the IET. As Chief Scientific Advisor for the Department for Transport it is important for me to be kept abreast of the latest developments in areas such as safety, congestion reduction and automation. However, it is also important the engineering, science and technology community do not always 'reinvent the wheel' so to speak and we as professional engineers learn from best practice and are able to and transfer this learning to other fields, and in the case of transport, to other modes.

Hence I find the findings and recommendations from the IET on cross-modal learning a refreshingly informative piece of work to contribute to the fast moving field that is transport and intelligent mobility. What we can learn from the report is:

- The opportunities across the transport modes - road, rail, aerospace and maritime - are immense and wide ranging but cross-cutting technologies are not often developed or even considered outside of each specific industry.
- Autonomy is already being widely used in our transport network and it is helping to increase efficiency and accuracy, travel longer distances, and go through regions that are not safe for humans to travel in (for example in marine).
- Different modes of autonomy have much to learn from each other in terms of R&D, skills and systems integration.
- There is an opportunity to bring together experts to share knowledge and provide technologies and innovations across all transport sectors for the benefit of all, including the end user.
- Regulators from different modes of autonomy can work together to develop a common approach to autonomous regulation and software standards across all transport sectors.

Moreover, the UK is one of the leading countries where innovators and companies from around the world can come together to test and demonstrate their autonomous systems in a safe and well-designed environment. We have the opportunity to bring together users, different insurance industries and the stakeholders necessary to understand and deliver the 'whole system' to become a forerunner not only in autonomous technology but also in leading best practice inclusive design, insurance and standardisation and practical roll-out scenarios for autonomous systems.



Professor Phil Blythe
Chief Scientific Advisor, Department for Transport

Background

Society stands to gain significantly from the introduction of automated vehicles - safety, flexibility, independence, economic value and sustainability.

Automatic or remote operation of vehicles is not new and can be traced back a century in the air and decades on the railways. A common feature of all these systems has been their operation in segregated or heavily controlled space to minimise the risk to people and property. Whilst this has enabled a significant expansion in the use of unmanned military aircraft, undersea vehicles and in metros, the full exploitation of their value in all sectors has been limited by the inability, technically and legally, to let them 'off the lead'.

The various modes of transport (air, road, rail and sea) face the same basic technical, social, legal and ethical challenges in autonomy - albeit starting from different baselines and with varying degrees of complexity and scale. They all need to achieve some form of collision avoidance, secure and high integrity communications with the infrastructure, vehicle health monitoring and degradation management, and the ability to safely handle all contingencies.

These technical solutions will have to conform to industry standards, meeting both national and international regulations and legislation, and be insurable to have a positive impact on society.

The introduction of autonomy opens up great opportunity for the UK; both by addressing the pressing need to tackle the increasing congestion exacerbated by legacy infrastructure, and through capitalising on the skills and research of developing autonomous vehicles. The major prize is to develop an integrated transport system with compatibility and shared learning across the transport sectors.

A system of systems approach is needed to connect all the different disciplines, manufacturers and nations together. There is a limited window of opportunity for the UK to make an impact and influence the development of international standards and regulations in order to position UK industry, academic and service sectors to capitalise on the very significant potential of autonomy.



Introduction

Autonomous Systems have potential applications on land, sea and air in all transport domains. The earliest applicants, beyond the currently automated metro lines, will be in the air and sea because of the nature of their operating space. The air also benefits from a mature and highly regulated infrastructure that will make transfer into autonomy easier.

The basic principle of operation for all domains is the same, with the vehicle having a set of on-board sensors, a secure connection to the infrastructure, a level of on-board computing and an actuation system to control the progress of the vehicle. The partitioning of guidance and control between the infrastructure and the vehicles will be dependent on application.

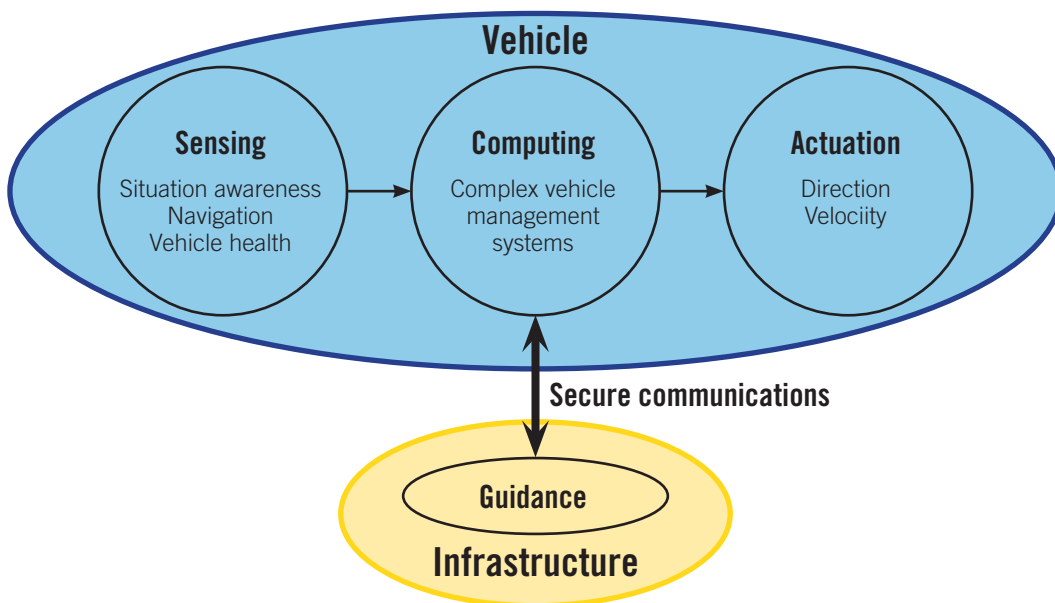
Operation in all of the domains will require a level of on-board intelligence to cater for any loss of communications - even temporary - with the external infrastructure. The infrastructure guidance point can be anything from remote pilot, a track signalling system or a traffic management system. Additionally 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 that will allow a graceful return to full operation with minimal operator intervention.

Although the principles are the same, there are significant implementation differences between different transport modes on how this

can work. For instance, the time constant for hand back of control to a human operator varies significantly from fractions of a second on the road to minutes in the air and sea. The response to failure also poses different challenges of how to bring the vehicle to a safe resting place. Air and undersea vehicles have the advantage of 3 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.

Another big challenge that adds further complexity is that automated vehicles will, in almost every case, have to share their environment with the current 'manned' vehicle stock. The initial approach has been generally to segregate the operational space and avoid mixing the vehicles. Whilst this has been practical for rail, sea and air, it would require major infrastructure investment to do this on the 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. 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.



Simplified Systems Architecture

The benefits

The benefits of a move towards more autonomous vehicles are broadly similar in all sectors - ultimately promising significant safety enhancements, more efficient transport, greater flexibility of operation and, potentially, reductions in environmental footprint.

Unmanned operations at sea and in the air open up new applications which are currently seem impractical or too hazardous for human operations (e.g. deep ocean exploration, extreme weather and long endurance airborne search and rescue, long term environmental monitoring).

On the road, autonomy offers greater independence to an ageing population, a means of tackling congestion and a step change in accident reduction. For the railways, autonomy can mean higher operating capacity and lower energy consumption.

As well as the major social benefits the introduction of autonomy is a multi-sector and multi-discipline opportunity for the UK manufacturing, infrastructure and services industry. The UK can build on the leverage of recent tests in autonomy to further enhance its position in research and development of autonomy.

As the issues are common across the sectors there is clear advantage to be gained from adopting a common approach to the legal, insurance and regulation issues that different modes of autonomy have. There is also a great opportunity, for individuals with transferable skills in communications, software development and cyber security to utilise their knowledge in autonomy.



The challenges

The challenges in adoption of autonomy are both technical and societal and apply to all the transport sectors. In theory, autonomy is about replacing the functions of the 'driver/pilot/captain' and taking on many of their responsibilities, including safe separation from other mobile and fixed obstructions, reacting to traffic management instructions, monitoring the health of the vehicle and, fundamentally, decision making.

Autonomy also requires a degree of external oversight and this will require sufficient high integrity and high security communications links to the vehicle; whether that link is to a remote 'pilot' or a traffic management system. To that end interoperability is a great issue in all modes of autonomy. There needs to be a level of standardisation in the systems of autonomy developed by manufacturers so that these links can be interoperable and adopted consistently.

Maybe one of the biggest challenges however is that in all spaces there will be a gradual progression to autonomy that will cause vehicles to have to interact with non-autonomous vehicles. In low density situations like air and sea static rules may be sufficient but as density increases the rules will need to change dynamically. Transition will take time and tests will help further technical developments; however, there will inevitably be a phase in the short term on the road where the introduction of autonomous vehicles will increase congestion.

Notwithstanding the technical challenges, there are also major social implications that need to be resolved. These range from legislation and insurance to public acceptance and ethics. Public perception needs to be managed effectively. There will be a natural scepticism about the adoption of automated vehicles, in some sectors, and a willingness to focus on any problems that arise along the way.

Challenge	Air	Road	Rail	Sea	Cross Modal Commonality
Technology	High	High	Medium	High	High
Regulation	High	High	Medium	Medium	High
Standards	High	High	High	High	High
Legislation	Medium	High	Medium	High	High
Infrastructure	Medium	High	Medium	Medium	Low
Insurance	Medium	Medium	Low	Medium	Medium
Public acceptance	High	Medium	Medium	Medium	Medium

Technical challenges

Challenge	Air	Road	Rail	Sea	Cross Modal Commonality
System Integration	High	High	Medium	High	High
Decision making (on-board)	High	High	Low	High	High
Safe separation (on-board)	Medium	High	Low	High	Medium
Safe separation (off-board)	Low	Medium	Medium	High	Low
Communications - infrastructure	High	High	Low	High	Low
Communications - security	High	High	High	High	High
Communications - spectrum	High	High	Low	High	Low
Cyber security	High	High	High	High	High
Traffic Management Systems	Low	High	Low	Medium	Low
Contingency management (on-board)	High	High	High	High	Medium
Energy management	High	Medium	Low	High	Medium
Vehicle health management	High	High	High	High	Medium
Human factors	High	High	Medium	High	High

Cross-modal learning

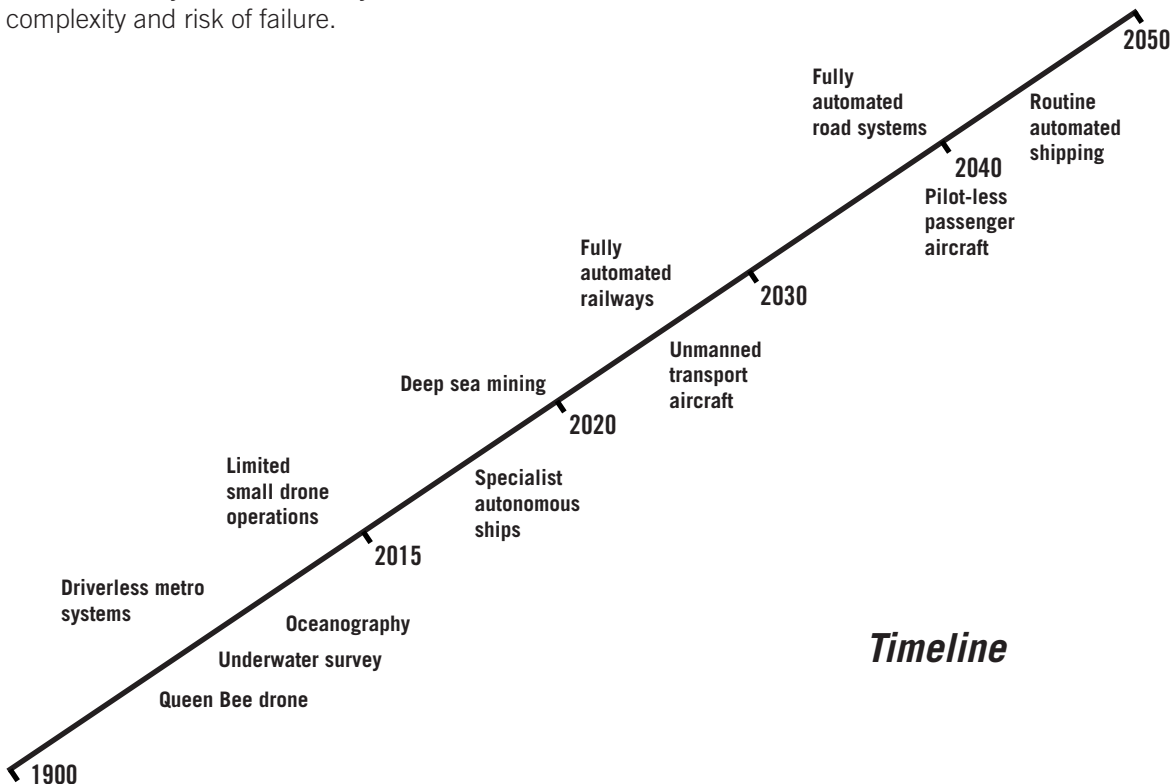
The potential of cross-modal learning in autonomy is vast. Many of the technological and legal challenges in autonomy between different transport modes are similar, allowing an opportunity for sharing of best practice.

Similarly, the approach to regulation could benefit from cross-sector learning and experience. For example, the safe separation distance between vehicles in air is well established through Air Traffic Control and it is relatively simple to adapt to allow for autonomy; whereas on the road adapting the traffic lights, speed limits and road spacing is maybe more challenging. Controlling safe separation (collision avoidance) off-board will be more difficult in road than other modes.

The integrity of the decision making system of autonomous software is also a major opportunity for cross-sector sharing and learning; and as this is a significant cost driver for autonomous technology a chance to reduce development cost. For example, a car today has ten times the lines of software code of a contemporary airliner and maybe 100 interconnected computer control units. The complexity of this system presents a major certification risk. By utilising the systems architecture and software segregation principles that are adopted in the aircraft industry, the car industry can reduce complexity and risk of failure.

In the air sector, there is a move from a class based system to a risk based system. The ASTRAEA programme developed a Virtual Certification process for unmanned aircraft that could be adapted for other vehicle types. It takes the document set from a fully certified 'manned' aircraft and adapts and adds to this the features required to make it 'unmanned'. This has the benefit of exploring all the certification requirements in a virtual space and allowing engineers to work with regulators on identifying the full set of approvals necessary in developing an autonomous vehicle.

There are also opportunities to learn from the interoperability of autonomous and semi and non-autonomous vehicles. There are differences in dimensional responses between different modes; air and sea generally have greater spatial and temporal freedom than road, but less dependence on the infrastructure. In the air sector, a variable autonomy concept is favoured, allowing for decisions to be made by a ground based pilot if time and the communications link allow, but on the road once in 'driverless' mode only full autonomy will suffice.



Timeline

Recommendations

1. Regulators of different modes of autonomy need to work together to develop a common approach to autonomous regulation and software standards across all transport sectors.
2. There are valuable lessons that can be learnt from different modes of autonomy that could challenge how software is being developed in autonomous cars currently. Professional bodies can bring together industry and regulators to encourage cross-modal learning.
3. Autonomous vehicles are not just about technical development. Before they can become part of our daily lives, we need to have a much better understanding of the behavioural and societal implications. This means there is a need for in-depth research and developing new skills within the autonomy industry.
4. An information campaign to help the public understand that automated transport already plays a major part in the UK transport system.

Appendix - The Sectors

Air

Unmanned aircraft have been in use in the military for the past 80 years and more intensively over the last 20 years. These aircraft are flown under strict operational rules and in airspace segregated from other air users. Interest is rapidly growing into the use of 'drones' for non-military state and commercial applications

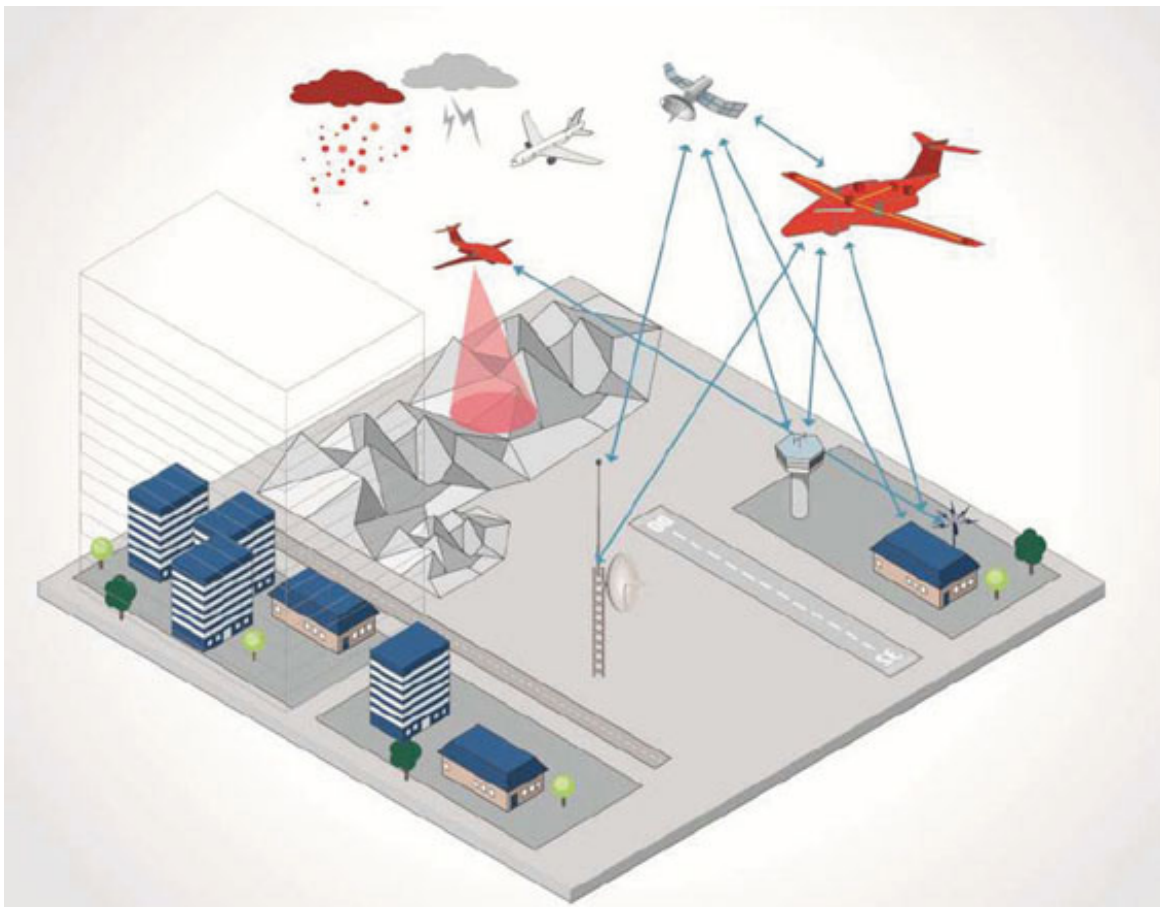
Where we are now?

The international regulations governing the design and operation of commercial aircraft currently assume that the pilot is on board the aircraft and there is yet to be an agreed re-interpretation for equivalent unmanned aircraft. As airspace will have to be shared by both manned and unmanned aircraft, any regulation for larger unmanned aircraft will have to be on a basis of transparency and equivalence. For smaller aircraft, below 150kg, regulation is currently the responsibility of national authorities. There is considerable international activity addressing the subject but much of this is currently directed at small vehicles.

In the UK, drones of less than 20kg are licensed by the CAA for aerial work providing that they are flown less than 400 feet above the surface, in direct line of sight and within 500 metres of the pilot and not within 50 metres of other people. There has been a rapid growth in licences for applications including aerial survey for agriculture and archaeology, TV & film, tracking and security, firefighting, infrastructure monitoring and oil rig inspection.

There has also developed a large market for 'hobby drones', cheaply available and outside the licencing authority of the CAA. These are subject to the same operating limits, but without the need for pilot licences or any form of registration, and there is growing concern over their misuse either accidentally or intentionally with consequent risk to other air users and members of the public and infrastructure.

The European Aviation Safety Agency (EASA) is proposing to move to a three tier risk based categorisation¹ of Open, Specific Operation and Certified.



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Challenges

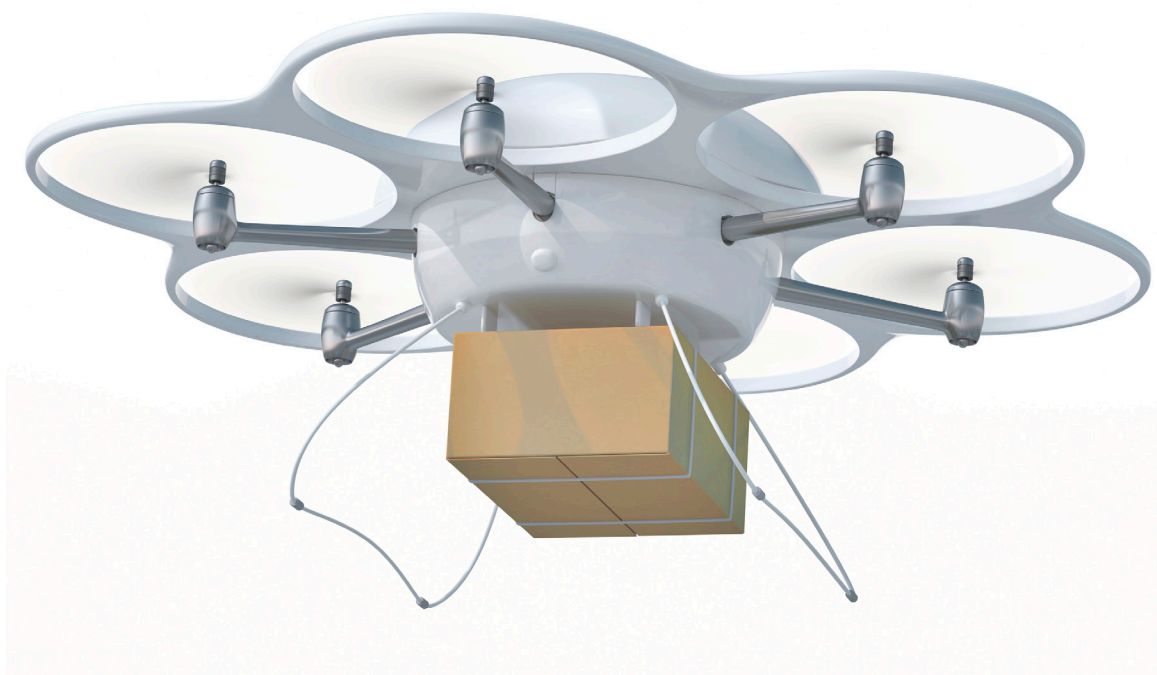
The challenges facing the expansion in the use of commercial drones are technical, regulatory and societal.

The technical challenges include all that is necessary to introduce drones into shared airspace without the need for major changes in the infrastructure or the equipment standards of existing manned aircraft. These include detect and avoid systems, secure and high integrity communication systems with appropriate spectrum and contingency management systems to deal with abnormal technical or weather conditions and provision for the safe termination of the flight. These basic technical requirements are applicable to most sizes of drone although the requirements become more complex and extensive as the size and operating envelope increases.

The regulatory challenges are to reach international agreement on the certification standards required for the drone system, the pilot and the operators such that the commercial exploitation potential is not just limited to the home market. This requires proactive engagement from the UK's industry and regulators in influencing the development of these standards.

The societal challenges include the development of legal frameworks, the provision of appropriate and affordable insurance and addressing the potential concerns of other airspace users and the general public.

Public concern appears to be more related to privacy issues than safety issues. ScienceWise are currently undertaking a public perception exercise on behalf of the government. The control of hobby drones will also need to be tackled and this will probably involve registration, education, and the introduction of technologies including geo-fencing and transponders.



Opportunities

Automation opens up the use aircraft for roles that cannot be undertaken or are considered to be too dangerous to undertake with a human on board. This represents a whole new opportunity for commercial aviation. Substitution of manned aircraft activity will only happen if there is a sound business case and where it has public acceptance (e.g. a new market segment for freight services using airships for global goods delivery that is faster than shipping but cheaper and with lower environmental impact than jet aircraft).

The main advantages from moving the pilot from the aircraft to the ground are:

- Safety - the pilot is not at risk (a key military driver) but also allows them to be operated in conditions that would be considered unsafe for a manned aircraft (e.g. sampling volcanic ash clouds, doing searches in very inclement weather). The risk to the public and property on the ground does, however, still need to be considered.
- Vehicle design - without the need to carry a pilot all the restraints of size and requirements for life support are removed. This gives greater flexibility of design from minute to highly manoeuvrable vehicles and very high altitude operation.

- Endurance - aircraft range and endurance is limited by the pilot's duty period. This constraint is completely removed.
- Cost - small drones will have a significant cost advantage of undertaking similar activities to manned aircraft (e.g. archaeological survey) but the business case for larger vehicles is yet to be fully established.

The technologies in development for all drone operations to prevent airborne collisions and optimise mission trajectories will enhance the safety and efficiency of manned aircraft while reducing the cost of delivering a safe air traffic control service through automation of the request, clearance and execution of aircraft manoeuvres.

Larger drones will have to be able to operate seamlessly in all classes of airspace. Smaller drones operating beyond visual line of site will have to share the challenging Class G airspace with GA aircraft, gliders, balloons, police and ambulance helicopters, etc.



Road

Where we are now?

Automated systems that feature in the passenger vehicle industry currently only offer services to the driver. Whether that is a service to give turn-by-turn instructions when given a destination, a means for relaxing when cruising along restricted access roads or collision avoidance in an emergency. Such systems have been categorised by the SAE², BAST³ and NHTSA⁴, and describe what type of autonomy a vehicle would be allowed, given the level of system that it has fitted.

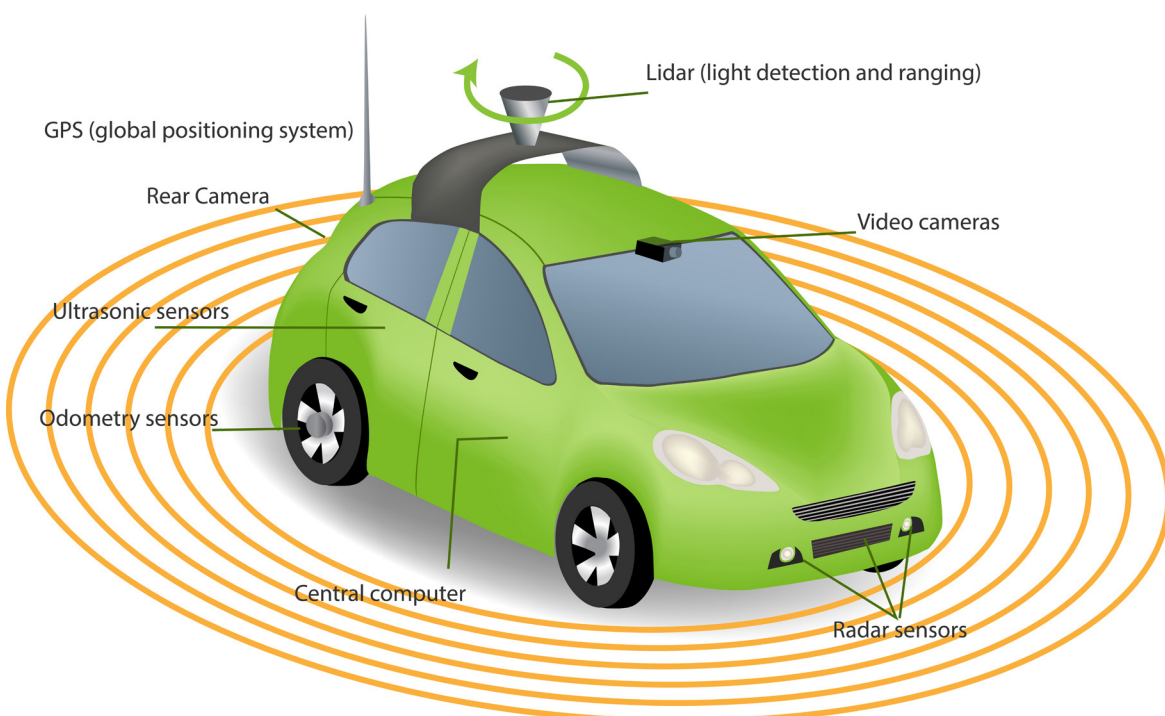
For example, Adaptive Cruise Control (ACC) provides a means for a vehicle to automatically travel up to a maximum set speed. The ACC will however reduce the speed of the vehicle if there is a slower moving target vehicle in its path. Once the target vehicle is no longer in-path the ACC will automatically resume to the set speed. This system is considered to lie at level 1 in all categories because it provides only longitudinal control of the vehicle. Another system that works in conjunction with ACC, called Lane Keep Assist (LKA) will ensure that the vehicle remains roughly in the centre of a lane on a highway by automatically adjusting the steering angle of the vehicle. In some circumstances this lane centring will be overridden temporarily, if the driver indicates to overtake the vehicle

ahead, or if the driver deliberately overrides in an emergency. This system (if used on conjunction with ACC) is considered to lie at level 2 in all categories because it provides both longitudinal and lateral control of the vehicle with the caveat that the system is supervised at all times by the driver.

Level 1 systems have existed in production vehicles since around the year 2000. However, level 2 systems are only just entering the market place and require the driver to supervise the system at all times. As the category level increases, the expectation on the level of driver supervision decreases; the end goal of “full automation” requiring no driver supervision at all.

Challenges

Current road vehicles fitted with automated systems make their decisions based on the speed and acceleration of other target vehicles. They try to understand what other vehicles will do based on their current behaviour, in order to continue or modify their own behaviour. They have no knowledge about target vehicle destination, their intended next step or their level of automation. All information on target vehicles is extrapolated, in order to perceive intention.



In order to make better decisions, target vehicle behaviour will be broadcast using “Car to Car” and “Car to Infrastructure” communications and used to truly cooperate. Standardisation in this area is being discussed in the “Car 2 Car Communications Consortium⁵” and operates at a European level. Worldwide harmonisation is an aspiration but is not specifically part of the scope of work. NHTSA are operating under a different solution called Safercar⁶, with broadly the same objective as the Car 2 Car Communications Consortium.

In order to progress beyond level automation 2 the industry requires activity in 3 key areas:

1. The ability to get much more information into the car and process it, so that it can be acted on appropriately. i.e. multi-sensor information being fused into something meaningful, so that systems can be aware of the situation and project what other vehicles will be doing accurately.
2. The ability to re-engage the driver appropriately from automated level 3. i.e. The Human Factors in driver handover. This will include taking the appropriate course of action if a driver cannot be re-engaged.
3. The ability to navigate and resolve vehicle position accurately. i.e. The creation (or downloading of) high fidelity maps that are updated when changes (like road-works) are detected, so that they are useful to other vehicles and matching what is sensed to that map to resolve position.

Opportunities

Over 90 percent of road accidents have as a contributory factor driver error. Autonomous systems can act faster and are more aware of their surroundings than a human driver and reduce the number of accidents on the road.

“Vehicle to Vehicle” and “Vehicle to Infrastructure” (V2V and V2I) communication will allow better transfer of information to the driver and passenger, and will keep the vehicle informed of the road ahead and possible congestion issues. This will make the journey more efficient and the vehicle part of a connected flow of traffic. The road-train concept whereby vehicles can join a platoon of traffic that will share information will allow the driver to disengage in order to rest on long stretches of road.

Autonomous technology will also open up new business opportunities and ownership models for the journey of passengers. There is scope for vehicles to not be owned by an individual but to be “called on” as and when needed and shared between various businesses and users.

The economic benefits of autonomous road vehicles are still imprecise and will depend on market penetration of the technology; however, studies have shown that the reduction of accidents will deliver significant economic benefits to cities⁷. Furthermore shared ownership and revised business models for vehicles have the potential to shift economic revenue structures in cities away from parking fees and congestion charging into a pay-as-you-go format.



Rail

Compared to other modes, the metro application, particularly in the form of Automated People Movers (APMs) have been running in an autonomous mode for many years. These generally tend to be found at airports (e.g. London Heathrow T5 to satellites, London Gatwick North-South terminals) however much more extensive versions can be found in on the Docklands Light Railway and in North America, for example Dallas Fort Worth and New York JFK.

This is probably attributed to the fact that railways in general (and certainly APMs in particular) are a fully segregated system and use vehicles with very similar braking and acceleration characteristics.

Where we are now?

A number of metros use autonomous systems for control and protection to achieve the desired headways. It has been shown that the TfL LU Victoria Line cannot achieve peak time headways when under manual control, however a train operator is present to manage the door open/closing, requesting train start and to be there to take over under failure conditions. On the mainline railways, there is very little automation, although Thameslink is expected to be the first mainline system to be fitted with Automatic Train Operation for the central sections, again this is purely to achieve headways.

Therefore it can be seen that in these key areas where the railway is fully segregated and the traffic is very similar then autonomous vehicles will continue to be developed and will probably extend to larger metro systems, although there will always remain the issue of how to recover the train in case of failure.



Challenges

It is unlikely, even in the long term that main line trains will become autonomous for the reasons of recovery following a failure (the difficulty of getting staff to a failed train by any other means of transport) and that trains can have such widely differing characteristics and finally with steel wheel/steel rail a human is required to judge those conditions and drive accordingly.

With regards to regulation, the railways have evolved through train protection systems to auto-driving systems and ultimately fully automated systems. There are many existing standards in Europe and the US that define the requirements for automated railway systems. Thus the regulators are generally relaxed with the systems in use at present; however moves to an autonomous mainline or at higher speeds will require significant effort to gain approval.

Opportunities

Automated rail vehicles already play a major part in the transport system and have helped increase capacity significantly. The autonomous systems on the Victoria Line on London Underground have allowed capacity to be pushed to 34 trains per hour during peak. Thameslink is also due to become the first “heavy rail” in the world to use Automatic Train Operation.

The potential opportunities in autonomy occur when we can consider it acceptably safe to have a train with no staff at all; currently on the mainline trains systems exist to offer guidance to the driver for when to coast, based on the movements of trains ahead, in these systems it is then still up to the driver to control the train speed manually.

Possibly the most automated part of the signalling system of main line railways is in the Control Centre where Automatic Route Setting (ARS) is in wide use and can amend routes based on train running information to maximise the capacity of the line/station. This will probably become more important as the Network Rail Control Centres take on larger areas and automation will be required to identify the most advantageous solutions.



Sea

The UK's position as a maritime nation, both politically and reputational, makes Maritime Autonomous Systems and autonomy technologies attractive both to the defence and civil sectors. As a world premier navy, the Royal Navy is a market brand that can be leveraged, in its widest sense, concurrently as autonomy is adopted by the RN. In addition the UK has strong maritime industry and academic credentials with comprehensive facilities around the UK coastline with access to the skills and services required to develop and exploit Maritime Autonomous Systems. The UK also has a global lead in the civil and insurance sectors which can be exploited to broaden the use of the common technologies and assist with negotiations with regulators to frame the use of autonomy.

Where we are now?

The Application of Marine autonomy spans the whole of the maritime domain. In the scientific sector, long endurance sensing will see a leap in our understanding of the marine environment, supporting sustainable resource use in areas such as carbon capture and habitat monitoring. For the global offshore energy market, the improved ability to both gather data and intervene using autonomous systems will reduce risk and cost while opening up exciting new operating environments. The military applications for autonomous systems

are integral to naval capability programmes from minehunting to augmenting submarine operations. Within the marine transport sector, autonomy has the potential to improve the integration and effectiveness of both cargo and passenger transport, including enabling export business into and out of the United Kingdom.

The UK has a global reputation for competitive related products and services with 3 of top 10 Remotely Operated Vehicle (ROV) manufacturers accounting for 21% of all ROVs sales in 2000-2010. In addition we have 7 top ROV/Autonomous Underwater Vehicle component manufacturers and a vibrant Sub Sea Technology Industry.

The UK National Oceanography Centre operate a wide range of autonomous systems covering Surface, sub-surface and glider technologies, these are used for ocean science.

Challenges

Standards and Regulation: developing a UK national maritime policy and strategy that will focus on developing the regulatory framework, safety management of MAS, risk analysis and mitigation and Certification regimes. Essentially, developing the UK as the centre for thought leadership on regulation and standards, supporting technology development,



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demonstrations and assurance. Under the Marine Industries Alliance a UK MAS Regulatory Working Group comprising operators, designers and regulatory authorities and trade associations, has been formed to address these issues. A draft Code of Practice has been developed and work is underway to develop this for application across the UK Industrial Base. Through the support of the UK Maritime and Coastguard Agency an Information Note on UK activities has been presented to the International Maritime Organisation, with a further paper to be delivered in 2016.

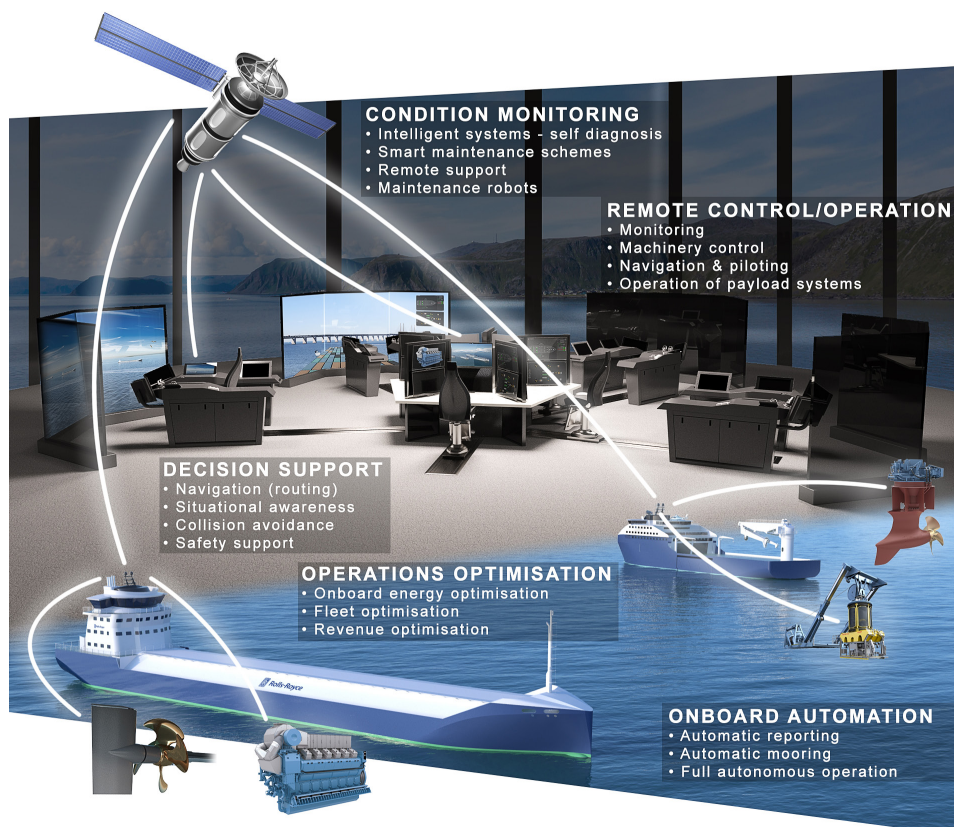
Skills: Identifying, developing and sustaining UK skills to enable the design, operation and management of MAS in the UK and internationally.

A critical element of the approach is the ability to link between these three areas for example demonstrating technologies that build confidence that the application of Autonomy can help resolve regulatory issues and that the appropriate skills and training is available in a timely manner to enable the operation of autonomous systems.

Opportunities

The use of autonomy in the marine domain is set to see a significant increase in the future. This will take the form of major growth in the use of interconnected intelligent systems which reduce manning to the point that completely autonomous surface and underwater vessels/platforms become accepted. The development of new products and services required to support this scenario, will provide vast opportunities for an array of SME and large companies in multiple markets, with significant export potential.

The maritime sector provides 2.1% of the UK's GDP and is an important part of UK industry, with good representation of SMEs. It is reasonable to believe that the UK can corral its capabilities and compete at the equipment, systems and system of systems level, which in turn will lead to the creation of jobs throughout the value chain, from design through manufacturing to training and service provision. Given the ability to exploit technologies, regulatory positions and skills, it should be possible to work across UK industry to take advantage of technologies developed inside this sector, as well as to exploit other advances in



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related sectors and generate Intellectual Property for the UK. It has value to both defence and civil activities that are *Dull, Dangerous* and *Dirty*, building on Autonomy as a disruptive technology. The MAS will provide critical strategic value with major economic benefit harnessing disruptive technology and transforming maritime operations.

Technology and Capabilities: exploiting unique UK strengths in key elements of technology matched against an improved understanding of the capabilities required in each of the principal market sectors applicable to MAS. Through Innovate UK, we are developing a series of projects via mechanisms such as collaborative Research and Development calls, to support the development of new ideas and to help mature emerging technologies from the UK MAS Science and Technology Base. As part of this a wider awareness of initiatives and innovations in other areas of Autonomy is being conducted to ensure that cross sectorial and multi-use technologies are identified and exploited. This will lead to the large scale demonstration of MAS demonstrator in a demanding environment, addressing wider aspects such as system of systems integration in a mix of autonomous and traditionally operated marine vessels.

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