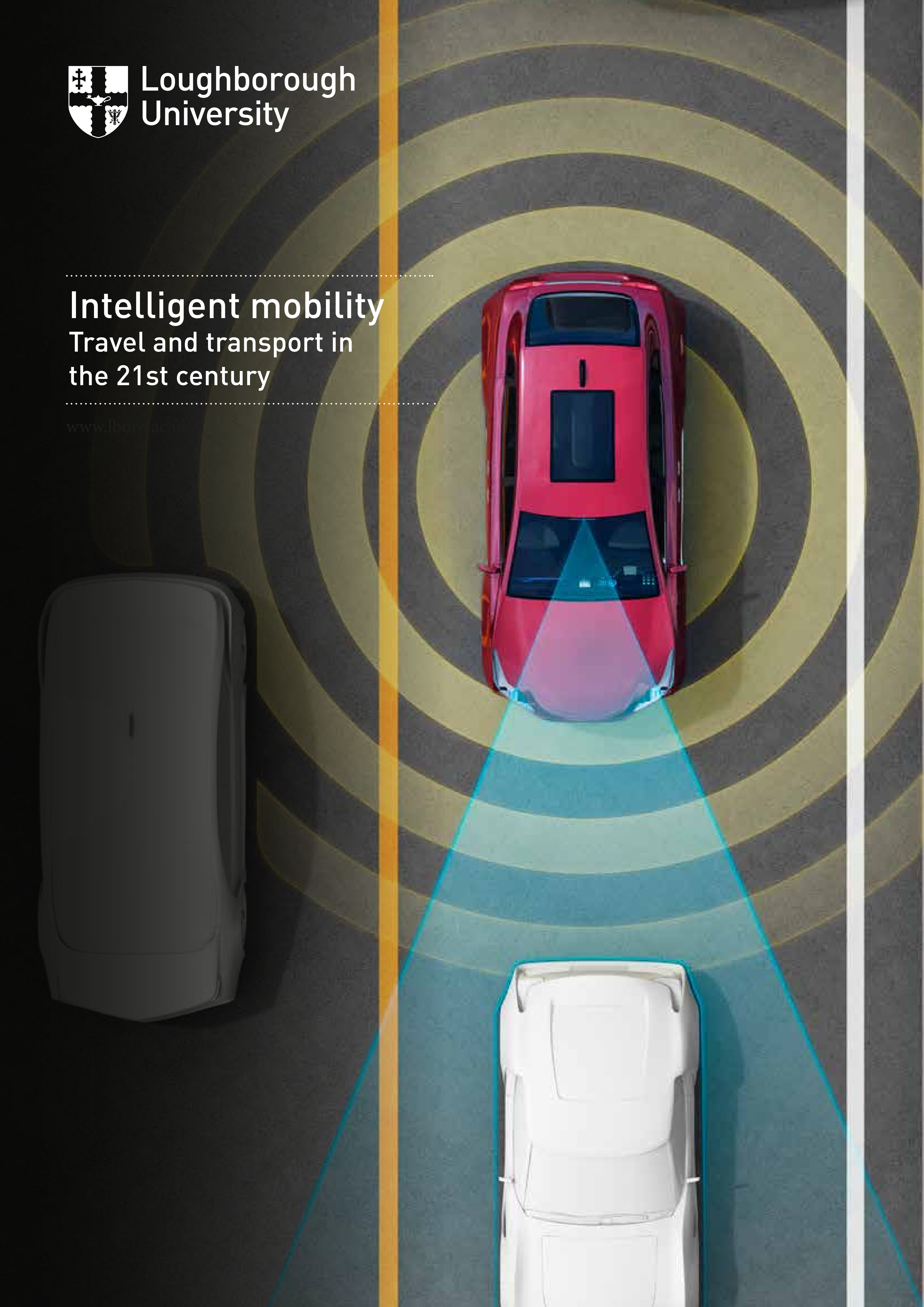
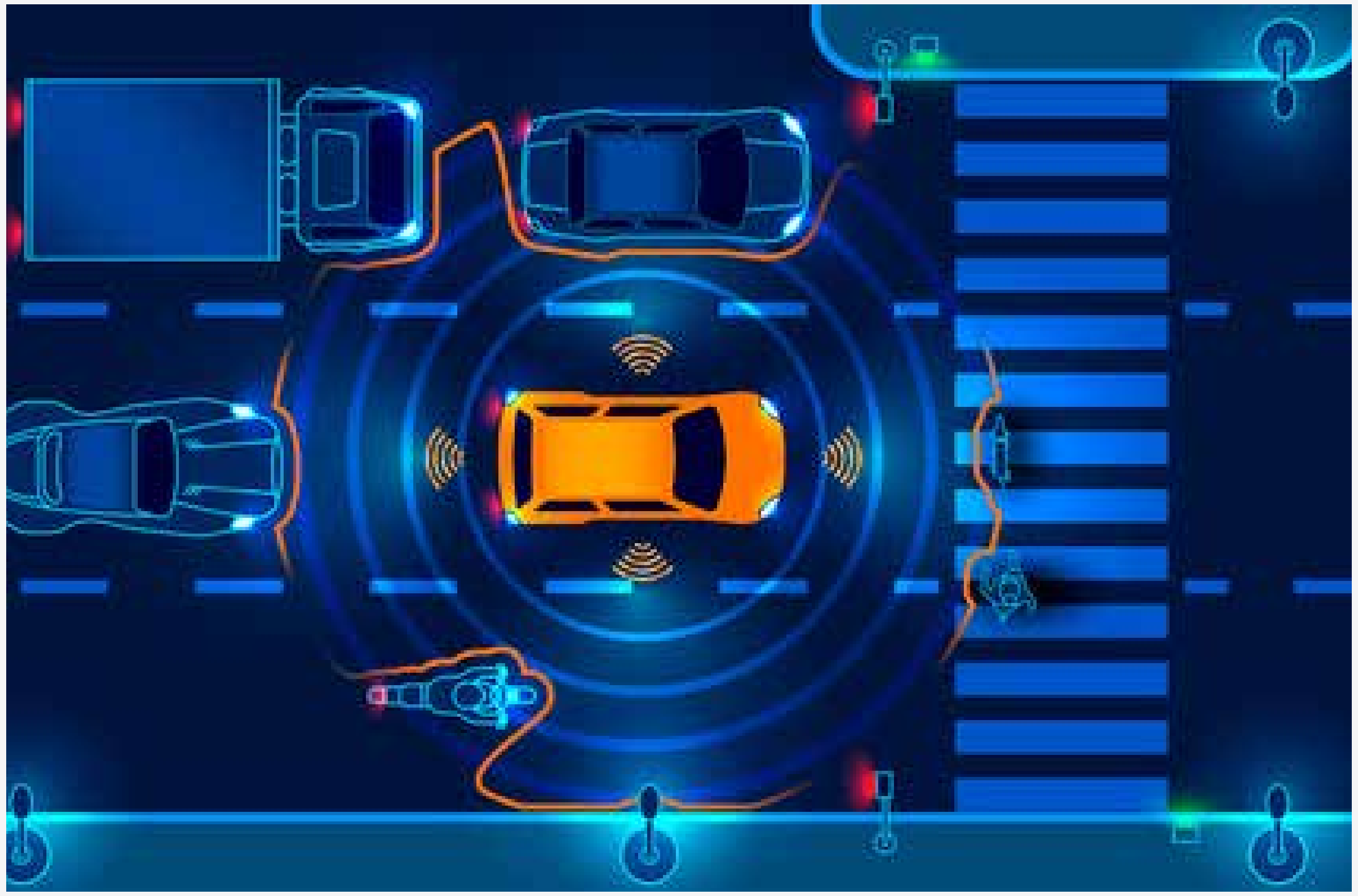
Loughborough University

Intelligent mobility

Travel and transport in the 21st century





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Welcome

Loughborough University is renowned for the breadth and quality of its vehicle and transport research – leading the way in many aspects of the low carbon, transport safety and autonomous vehicle agendas.

Our current transport-related research portfolio totals £90 million, and amongst our accolades are seven prestigious Queen's Anniversary Prizes, in recognition of our world-class research excellence.

Our long-standing industrial partnerships allow us to work closely with some of industry's key organisations including Rolls Royce, Jaguar Land Rover, Ford and Nissan.

Our intelligent mobility research spans multiple disciplines, exploring the physical and virtual engineering elements as well as the human factors and transport planning aspects of this emerging sector.

Intelligent mobility is more than simply an enabling technology. It represents a revolution in modern transportation, spanning in-vehicle, vehicle-to-vehicle and vehicle-to-infrastructure intelligence – across all modes of transport.

Crucially, it should put the traveller at the heart of a co-ordinated transport network, ensuring the most efficient end-to-end travel experience that has low environmental impact. User acceptance is key to intelligent mobility deployment: the development of new connected and autonomous vehicles, performing under real-world conditions, is of major societal concern.

At Loughborough, we are reimagining the shape of new infrastructure across the transport sector – enabled by data, technology and innovative thinking. By deploying our unique combination of capabilities, we can transform how we move people and goods whilst increasing the efficiency, sustainability and safety of our transport systems worldwide.

Martin Passmore
Professor of Automotive Aerodynamics

One University, two impressive locations

Loughborough University has two campuses – its superb 440-acre home in the Midlands and its modern development in London. Both offer outstanding research facilities, technical support and access to world-leading expertise.

Expertise and facilities on our main campus enhance our position as one of the UK's leading centres for education, training and research for the rapidly growing intelligent mobility industry. These include our Autonomous Systems Laboratory, the Caterpillar Innovation and Research Centre, the Loughborough Advanced VR Research Centre and our expert field trials team who assess driver behaviour in real time.

Loughborough University London, based on the Queen Elizabeth Olympic Park (QEOP), is part of the city's new innovation quarter, Here East which also hosts Europe's largest innovation centre, Plexal. The QEOP is rapidly becoming a national centre for intelligent mobility with the launch of Ford's new Smart Mobility Innovation Office and the relocation of the HQ of Transport for London.

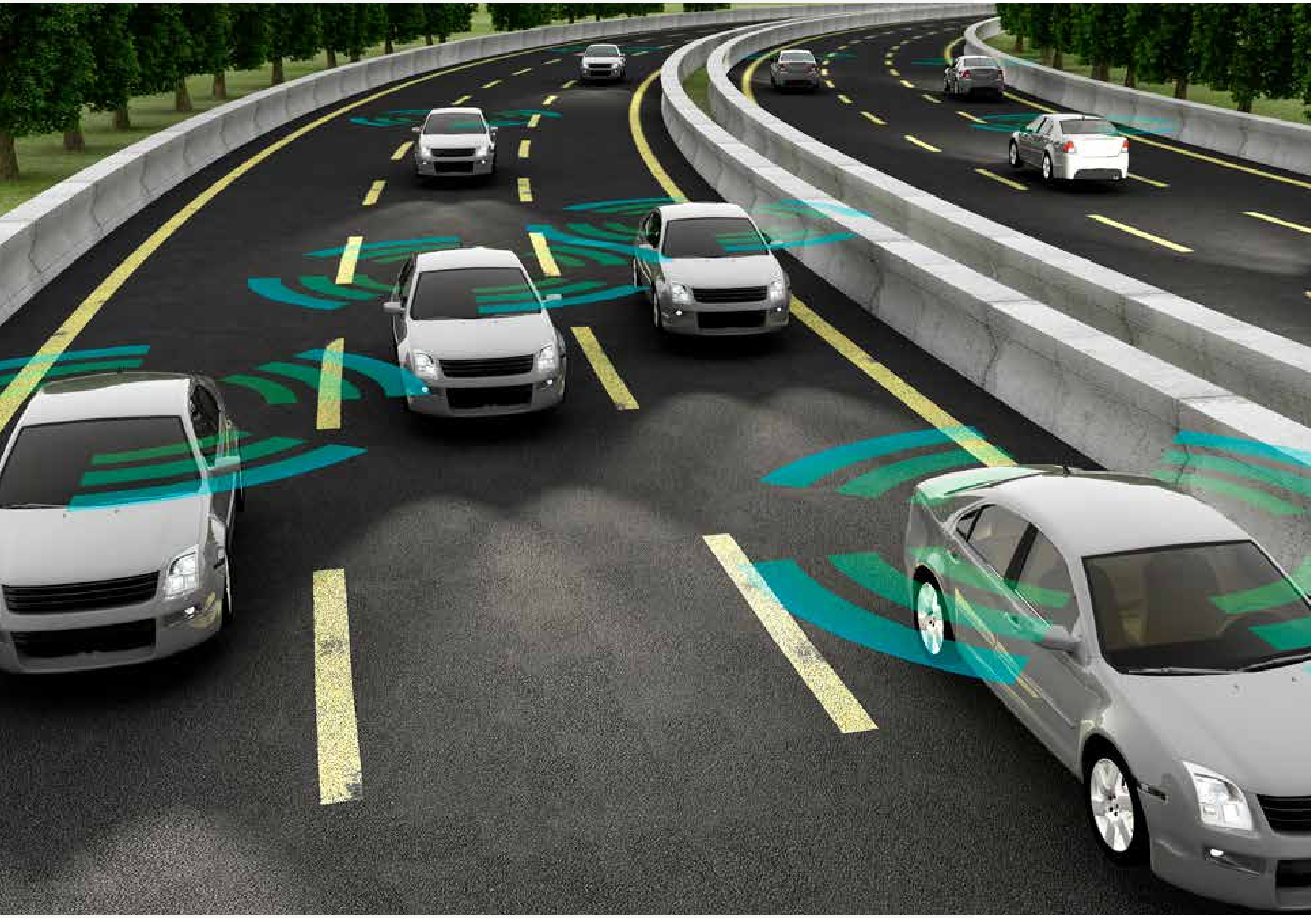
Our London campus enhances our existing world-class partnerships and excellence in research, particularly in digital technologies, and is home to the Digital Engineering and Test Centre (DETC).

Delivered in partnership with the High Speed Sustainable Manufacturing Initiative (HSSMI), the DETC is an Advanced Propulsion Centre (APC) spoke. It is a unique collaboration of industrial and academic experts whose unrivalled skills and knowledge are supported by world-class research facilities. Their remit is to halve the time and cost of the development and test of next generation powertrain systems and vehicles.

Virtual engineering

Increasingly, R&D relies on simulation and modelling – enhancing the speed and reducing the cost of development.

As engineering shifts into the virtual realm, greater experience, resource and skills within the digital domain are required – on the one hand to explore, test and validate new concepts and products; and, on the other, to ensure the safe and secure deployment of them.



Connectivity and system engineering

The evolution of connected and autonomous vehicles (CAVs) demands ever more complex systems to support and control them.

Our research in this area is guided by three key factors – dynamics, uncertainty and safety – and explores a range of issues, including:

Driver-machine integration

Our work around driver modelling and characterisation supports systems, ensuring the safe and timely transfer of control between autonomous and driver modes. Underpinning the emerging science of allocation of function is the development of machine learning. Our expertise in driver behaviour recognition and distraction detection has allowed us to create systems that recognise patterns of driver behaviour and identify abnormal activity. Personalisation through machine learning tailors driver behaviour monitoring for individual driver style and personality, improving reliability and safety. In this way, human fallibility is minimised and safety, optimised.

Dynamics

The development of systems that support decision-making and situational awareness has allowed us to explore how to make road travel more efficient and less polluting. Drawing on our expertise in vehicle dynamics, we are able to model the reduction in drag and emissions when CAVs travel in convoy. This mode of travel has the added advantage of improving vehicle stability whilst reducing urban congestion. We are also working toward two-wheeled CAVs, focusing on improving stability and safety. This will help to increase acceptance of these vehicles which, due to their small footprint, offer reduced congestion and pollution.

Robust decision-making

We are developing a range of decision-making support tools – including optimisation algorithms, planning and scheduling tools, and anytime algorithms for real-time implementation. Based on model predictive control, the receding horizon concept allows us to create systems that predict and determine action, taking into account situational uncertainty. By working incrementally – making small, short-term adjustments to, for example, speed and direction – these systems ensure robust decision-making within an ever changing driving environment.

Situational awareness and automated optimal avoidance

We have made significant progress in developing systems that support collision avoidance – even at high speeds in environments where multiple objects are moving, often erratically. By modelling interactions between road users and their environment we are able to reduce uncertainty and support the decision-making process – making autonomous vehicles safer and more reliable whatever the driving environment presents.

Sensor-based and machine learning algorithms for road user detection and situation interpretation have been investigated to deal with some challenging situations in natural driving, including joining a roundabout and passing a road junction. An efficient grid-based learning method has been developed to incrementally learn personalised control strategy to deal with road situations. Verification and validation of learning systems for autonomous driving are also being investigated to make sure the learned control strategies meet the regulation requirement for safety critical systems, for example, ISO-26262.

Cyber security

Connected and autonomous vehicles (CAVs) provide a raft of benefits that enhance travel, making it safer and more comfortable.

However, as vehicles become more connected and autonomous, they become more vulnerable to potential cyberattack.

The range of possible threats is varied and unique to the new phenomenon of car-as-computer, spanning data and identity theft, insider attack, and automotive "hacktivism".

Misinformation maliciously injected into the transport data network – regarding fictitious incidents on the road ahead – could disrupt vehicles, causing delays or accidents; potentially bringing an entire transport network to a standstill.

We have more than a decade's experience developing intelligent networks to ensure their reliability and security – futureproofing systems and safeguarding against this kind of malpractice.

We are applying our expertise in network defence, privacy protection and secure data storage and access to vehicle cyber security, and our current research in this area focuses on anomaly detection in CAVs, spanning:

- intrusion detection for vehicular ad-hoc networks
- vehicle system attack detection
- data analysis to verify the integrity of the CAV environment
- verification of critical actions and manoeuvres.

Put simply, by combining cross-layer communication protocol measurements and contextual vehicle sensor information, we can teach the vehicle communication environment to identify and reject bogus data.

Advanced computing

Electronics are increasingly underpinned, not by conventional processors, but by system on chip (SoC) technology.

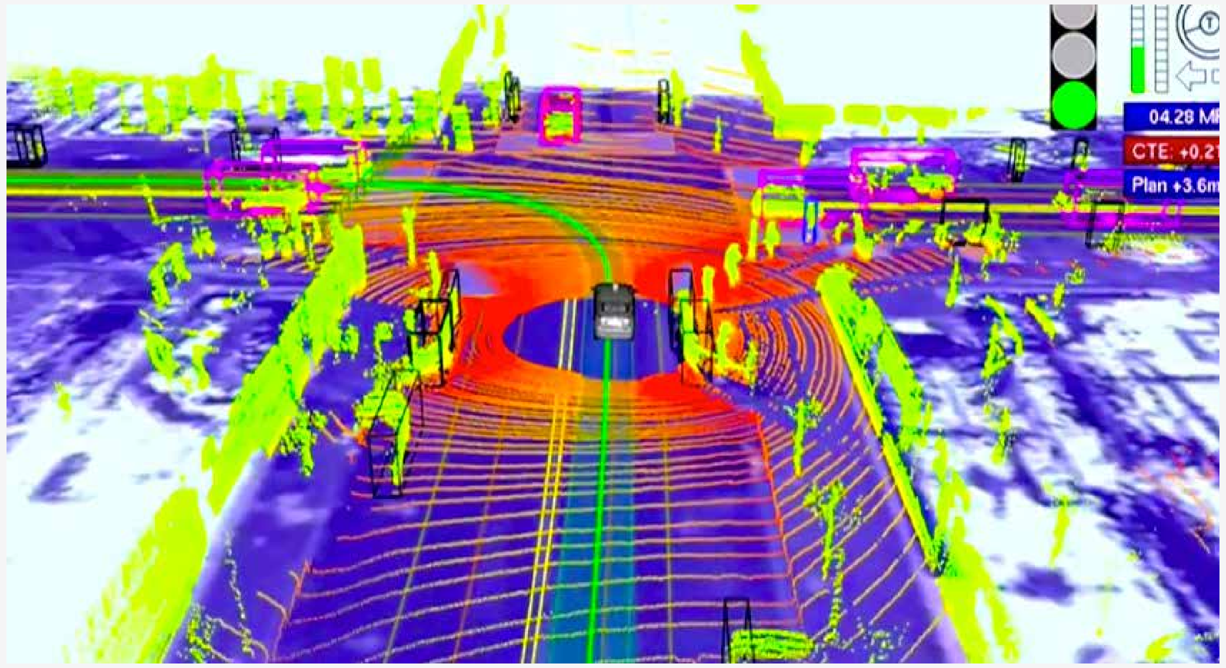
Modern automotive embedded systems – spanning ABS, electronic stability control, traction control and automatic four-wheel drive – all rely on SoC.

We have made significant advances in the development of SoC capable of interpreting image data and generating associated metadata.

The potential applications and impacts of this technology within the modern automotive sector are huge.

By developing computer vision and data interpretation in tandem with machine learning, we can create powerful systems to support autonomous situational awareness and robust decision-making. Reading road signs whilst recognising vehicle types, roadside furniture, pedestrians, animals, road type and layouts will make machine decision-making systems more reliable and robust in real time.

We are also exploring how SoC technology could support studies of driver behaviour and vehicle autonomy to underpin developments within allocation of function.



The Loughborough Advanced VR Research Centre

The Loughborough Advanced VR Research Centre is the longest established Centre of its kind in a UK university.

Spanning more than two decades, our pioneering virtual engineering research combines model-based engineering, big data analytics, co-simulation and system architecture.

Based in a state-of-the-art advanced collaborative environment, we have the expertise and resource to develop projects from concept to architecture creation, optimisation, co-simulation, design space exploration and, ultimately, deployment.

Crucially, we can provide early virtual validation of concepts and test scenarios – making the development of new technologies more cost effective and time efficient.

Virtual validation and verification

The validation and verification (V&V) of autonomous systems poses a range of complex challenges.

Our transdisciplinary team is developing new test methods to assure stakeholders that autonomous systems function correctly under the full range of real-world conditions.

Whilst physical testing continues to be useful, the proliferation of conditions and variables means that new virtual methods are needed.

Our work demands a comprehensive understanding of the behaviours of CA and fault detection algorithms and is pulling together various existing V&V methods to provide a complete, fail-safe solution. To date, two specific V&V techniques have been developed: automatic worst case search and reachability analysis.

Given the high risks involved, in particular for safety critical systems, V&V must take place at component, function (sub-system) and system level with various iterations at each.

Research is on-going, but we are well on the way to defining a robust and reliable test method which has applications well beyond our original remit.

Physical engineering

It is predicted that conventional internal combustion (IC) engines will continue to be the prime propulsion system for road vehicles for the next 20 years at least.

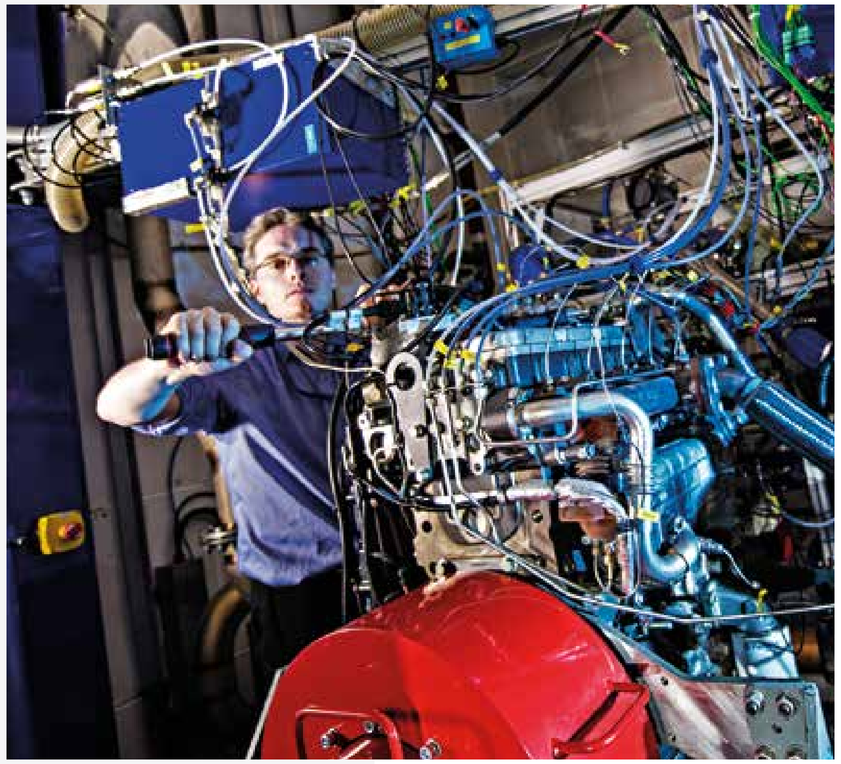
The development of ever more efficient and sustainable engine technology is therefore imperative – as is the adaptation of powertrains in response to the IM agenda.

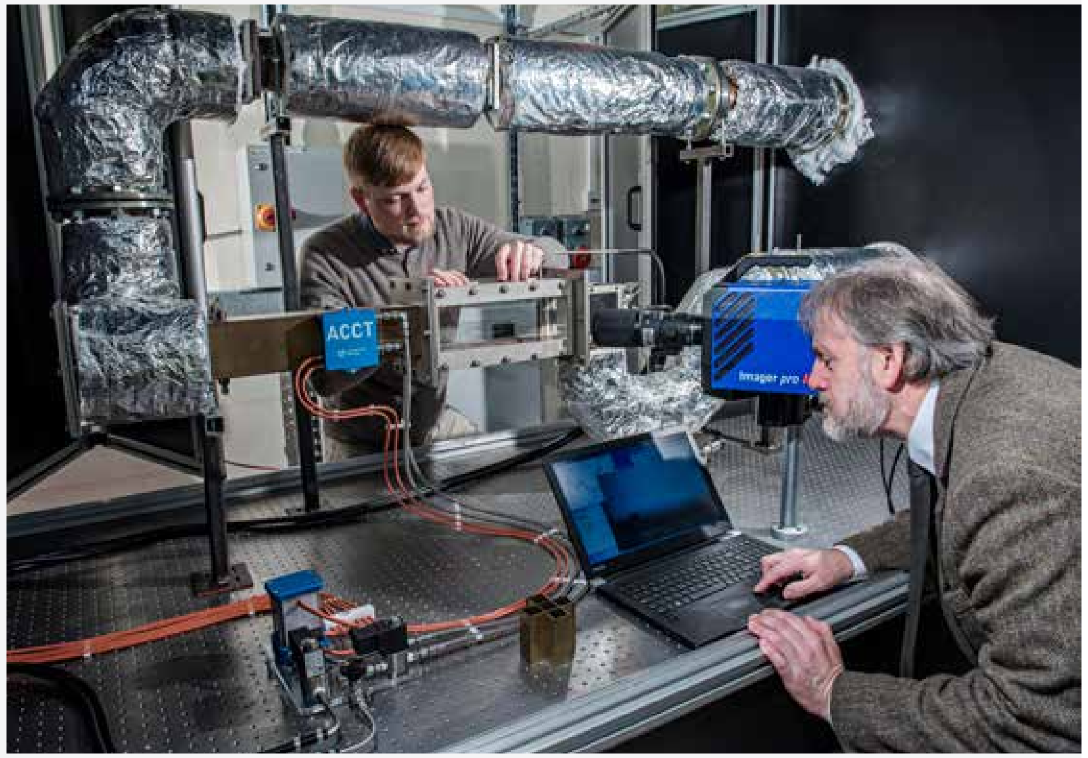
Our team of engineers is a significant leader in the field of engine and propulsion technology. Their expertise spans after-treatment, combustion, dynamics, engine control, fluid flow, optical diagnostics, and tribology. Much of their research is trans-disciplinary, requiring collaboration with specialists in materials, manufacturing, plasma and pulse power, renewable energy, and systems engineering.

Their work is supported by a dedicated team of technicians and advanced research facilities including an Engine Powertrain Laboratory comprising eight engine test cells, emission analysers, dynamometers, multi-cylinder and optically accessed engines.

They have the expertise and capability to develop the effective integration of electrical systems within the powertrain to support cooperative vehicle control and calibration as well as energy planning.

An increase in autonomy also delivers additional opportunities for enhanced emission reductions. For example, there is much to explore around the automatic triggering of a shift from IC to electric powertrain within geo-fenced, high-pollution areas.





Unmanned autonomous vehicles

Autonomous vehicles have the potential to revolutionise how we travel, transport goods, deal with hazardous situations, explore hostile environments and conduct warfare.

Our work addresses the machine intelligence required to ensure their safe and efficient deployment.

Truly transdisciplinary in nature, our expertise spans aerospace, agricultural and environmental sciences, computer science and engineering. Our current research falls into three key themes which tackle both current and future issues around machine autonomy.

Development of unmanned aircraft system technologies

We are developing advanced algorithms and methods for controlling unmanned aircraft systems including autopilot, autonomous taxiing, situation awareness, path planning, and decision-making. These technologies not only increase the level of autonomous intelligence of unmanned aircraft, but also support the safe operation of vehicles by human pilots.

Safety of unmanned aircraft system technologies

Our research in this area includes the development contingence management to enable safe operation of UAVs and, more importantly, the development of new techniques to support verification and validation of new autonomous functions and systems to provide assurance.

Applications of autonomous system technologies

This is a growing research direction, including the applications of artificial intelligence, data mining and autonomous system technologies in a wide range of sectors, from intelligent mobility and defence to agriculture and environment monitoring.

Engine powertrains

We have long-standing partnerships with a range of global collaborators including Caterpillar, Continental, Ford, Jaguar Land Rover and Lotus.

By addressing the competition between the drive for superior fuel efficiency and reduced emissions with the desire for ever-greater performance, our work has advanced automotive powertrain design, resulting in improved vehicle refinement and enhanced driver experience.

Our work has also helped our partners to reduce production costs and improve efficiency across the full R&D life-cycle.

A range of projects has established the University as a partner of choice within the sector. These include:

- Project HOTFIRE which developed a DISI engine system with fully variable valve timing and lift, achieving a 15% reduction in fuel consumption
- EPSRC-funded project, Encyclopaedic which investigated piston-ring / liner interactions to reduce the piston parasitic and errant dynamic losses
- Turbo Discharging which has resulted in a new patented IC engine air system that improves fuel economy, reduces CO_2 emissions and increases engine torque
- Advanced Selective Catalytic Reduction (SCR) system research for reduced NOx emissions, including the patented ACCT technology

We have also developed advanced optical diagnostics techniques for IC engines that are used widely in industry, including Particle Image Velocimetry (PIV), Laser Vibrometry and TV Holography.

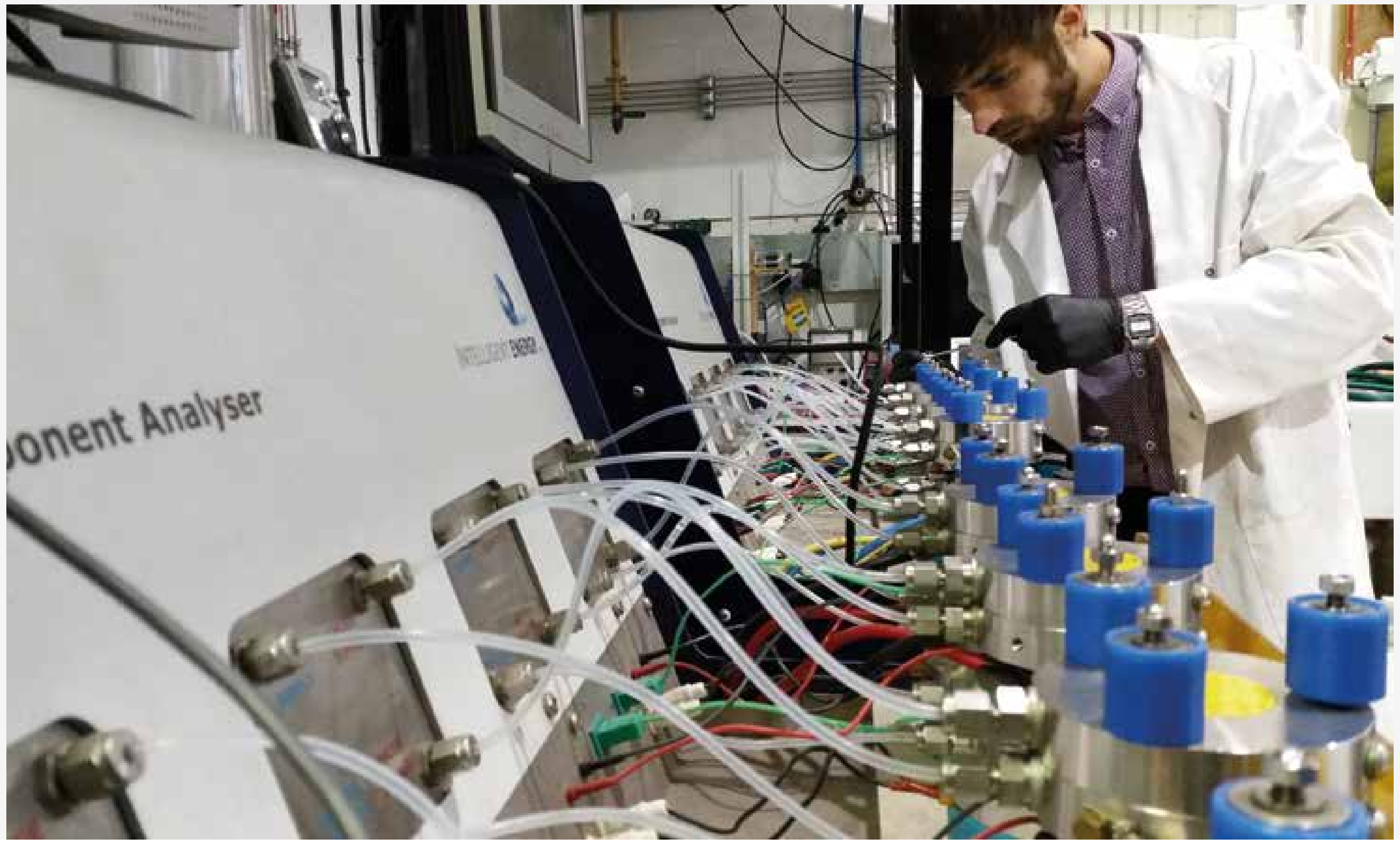
Low carbon power engineering

Our Low Carbon Technologies Group works with a range of partners to develop more efficient and less polluting powertrains.

The Group's expertise spans hybrid and electric vehicle technologies as well as conventional combustion systems.

Our fuel cell technology research dates back to the late 1980s. In 1995, our researchers constructed the first 1kW proton exchange membrane fuel cell. This pioneering work underpins a new generation of clean power systems.

Our activity includes leading the EPSRC-funded FUTURE Vehicle Project and ELEVATE. These aim to develop the science of low carbon vehicle components – including batteries, supercapacitors, fuel cells, power electronics and electric machines – and control systems to extend conventionally perceived operating envelopes whilst avoiding premature degradation or failure.



Control Systems

Our Control Systems Group has an established track record for applied research dating back more than 40 years.

Working with a variety of partners – including BAE Systems, Co-Catalyst Limited, Jaguar Land Rover, SET Derby, Southern Rail, Telent, and Transport for London – to address specific challenges, their work has been funded by a range of bodies including RSSB and EPSRC.

Much of the Group's current research around transport focuses on the rail industry in line with the Digital Railway agenda – the industry plan to tackle the UK's rail capacity challenge. However, their research has wider applications across the transport sector as can be illustrated by four current projects.

Vehicle monitoring and prognostics systems

We are developing methodologies to monitor full bogie system condition. The algorithms and on-board sensor package in development will assess the need for maintenance as the vehicle negotiates the rail network. This move to automated, intelligent condition-based maintenance will reduce the time that rolling stock is out of commission, ensuring more cost effective and safer operation.

Faster, safer boarding and alighting

We are investigating ways to enhance the traveller experience by making train access easier. A key area of study is the use of advanced algorithms, sensing and actuation to automatically adjust vehicle height – in a manner similar to kneeling buses – so that train and platform height are levelled and platform gaps are reduced.

Repoint

Repoint is our revolutionary track switch that increases safety and enhances network capacity. They are currently developing the mechatronic design of this system and algorithms that will assess switch maintenance status, reducing the need for physical inspections and improving network efficiency and safety.

Vehicle-based switching

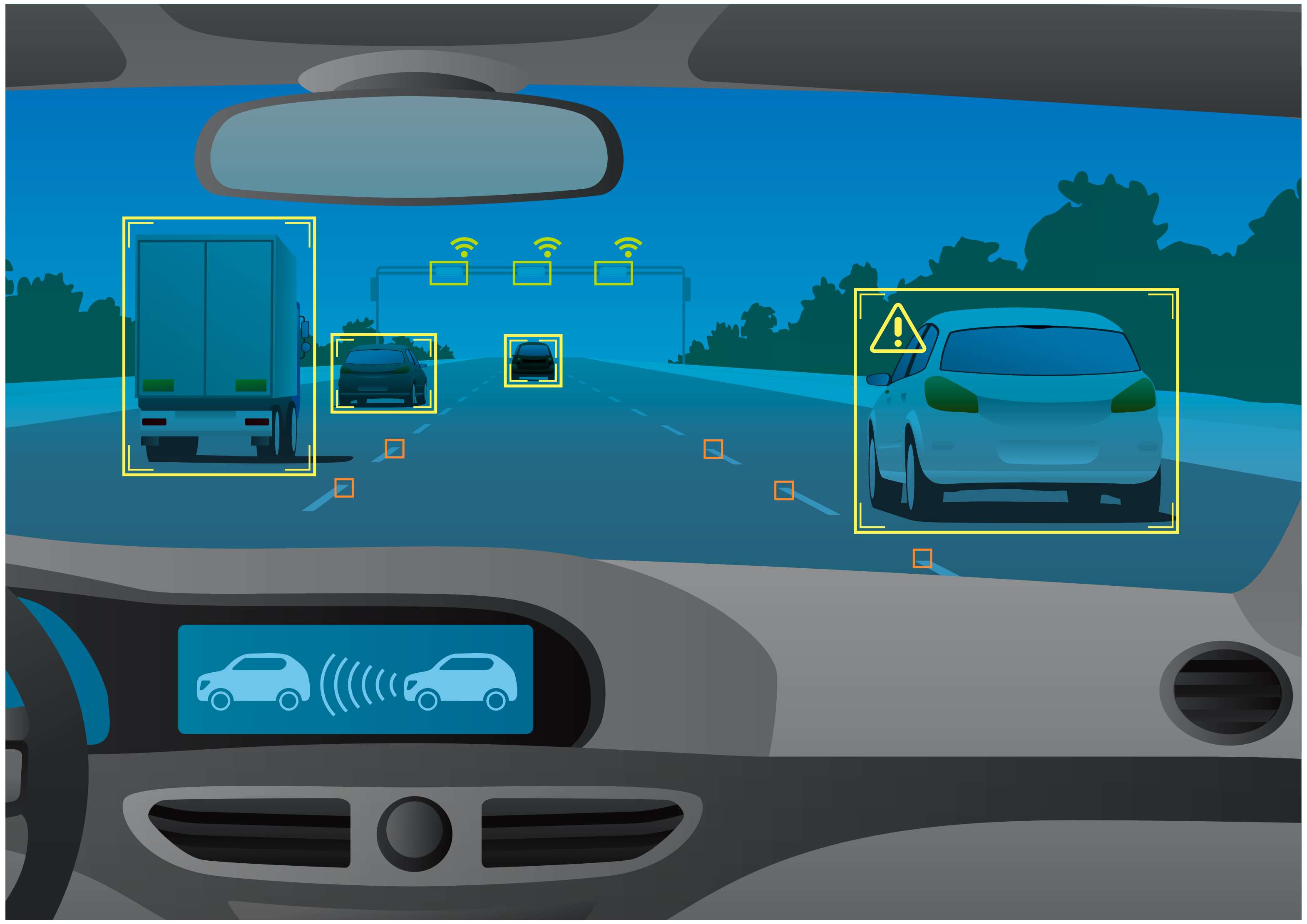
As part of the European In2Rail project, we are exploring ways to support vehicle-based switching so that route selection can move on-board the vehicle – rather than being controlled by the infrastructure. We are investigating self-steering mechatronic vehicle guidance technology that will enable this transition, making vehicles more autonomous and safer.

These solutions support the development of safer, less fallible systems for the rail industry. They also highlight ways in which systems technology can support vehicle safety and maintenance as well as navigation and route planning in semi- and fully-autonomous vehicles across the transport network.

Human factors and safety

The work of our Transport Safety Research Group is internationally renowned and has been recognised with a number of coveted accolades including a Prince Michael of Kent International Road Safety Award (2013) and a Queen's Anniversary Prize (2007).

Central to the Group's work is understanding road user behaviour and how this impacts transport safety and intelligent mobility. The Group has extensive expertise and experience in research methodology, in particular, analysis of safety and injury data.



Road user and driver behaviour

Our contribution to safety science is well-established, spanning more than 30 years. We are developing a comprehensive understanding of road user behaviour and how it impacts road safety.

A cross-disciplinary team, we have expertise in human factors, mathematics, mechanical engineering, medicine, and psychology. This broad-based capability allows us to study the complexities of road user behaviour from a range of perspectives and develop a comprehensive understanding of how it impacts road and vehicle safety.

Our research includes:

- road and vehicle design and safety
- driver and road user behaviour
- accident and injury causation
- injury biomechanics, outcomes and prevention
- human factors and design for behaviour change
- decision support and telematics data analysis.

Combined, these elements allow us to investigate the causes of accidents and develop innovative ways to reduce their incidence whilst striving to minimise injury severity and harm.

We have extensive research expertise, spanning experimental research methodology; field trials; and the collection and analysis of safety, mobility and injury data.

Our researchers make significant contributions to a range of international initiatives, and current projects include:

- SafetyCube – Developing a European Road Safety Decision Support System
- Vulnerable Road Users – Intelligent Transport Systems (VRU-ITS)
- SaferWheels – understanding the nature and causes of accidents involving powered two-wheelers and bicycles
- European Naturalistic Driving and Riding for Infrastructure and Vehicle Safety and Environment (UDRIVE)
- Road Safety Data, Collection, Transfer and Analysis (DaCoTA).

Safety in the age of IM

Intelligent mobility technology can improve safety and reduce accidents.

However, these same tools can introduce new risks and dangers.

Our research assesses the efficacy of new technologies, ensuring that modern vehicles are comfortable and protect their occupants.

Vehicle control systems spanning autonomous emergency braking, lane-keeping, speed adaptation and GPS navigation support the human driver, but can be a source of distraction or inattention as the workload changes.

Our research explores ways of managing the transfer of vehicular control between driver and autonomous systems and explores how best to ensure drivers remain alert, situationally aware and ready to retake control whenever necessary.

As new Advanced Driver Assistance Systems (ADAS) and partial automation develop, we must monitor what happens in the real-world, observing how driverless and ADAS vehicles behave on the road.

Our research encompasses both lab and applied work, comparing crash involvement rates of vehicles with and without the new systems. This entails:

- field trials of new in-vehicle safety and non-safety equipment
- measuring the limits of effectiveness of vehicle safety systems and ascertaining the conditions in which they best operate
- exploring the effects of advanced safety equipment and partial automation systems on driver behaviour
- analysing the types of accidents ADAS vehicles are involved in.

Our current projects include:

- **CAPRI** (Connected and Autonomous PODS on-Road Implementation) – we are conducting field trials of an autonomous pod shuttle service
- **RoboPilot** – for which we are developing and testing a robotic delivery service
- **IMPART** (The Intelligent Mobility Partnership) – a strategic relationship with the Transport Systems Catapult.

These studies allow us to make informed recommendations to industry on how best to introduce IM integrated safety technology into vehicles.

Machine emotional intelligence

As transport networks become more advanced and intelligent, successful human-machine interaction becomes a key operational requirement, both at physical and emotional levels. Machines will need to be able to read and anticipate human behaviours, and to interpret and understand emotions as well.

Our experts have developed sensing and analysis technologies – a combination of advanced hardware and software – that can read gross and fine motor activities. The team has also developed systems that teach machines to recognise human emotions and respond appropriately. These bespoke sensors and algorithms understand and assess human skills and performance, so that machine support can be modified to suit evolving situations.

The development of machines with emotional intelligence will underpin successful intelligent mobility technology and support system acceptance. It will also enhance safety. Recognising physical and emotional symptoms of stress in drivers would allow intelligent systems to diagnose and intervene more effectively to prevent accidents.

Enhanced mapping technology

Intelligent transport systems and services (ITSS) rely on high-quality real-time positioning data, in part generated by map-matching (MM) algorithms that ensure the data plots accurately onto the actual road network.

ITSS are used by a range of location-based services including navigation systems, vehicle safety applications, accident and emergency responders, and traffic analysis models.

However, the positioning many systems provide can be unreliable, particularly in areas where, for example, urban canyons, tree cover and tunnels hamper required navigation performance (RNP).

For the past decade, our Transport Studies Group has worked to enhance the reliability and accuracy of MM technology, and developed a number of knowledge-based intelligent MM algorithms that demonstrate greater integrity.

This work incorporates both lab and field work. Striving to achieve the best RNP, we have developed and assessed a range of algorithms, using a variety of approaches including fuzzy logic, probability, genetic algorithm and Kalman filtering. Following a period of simulation tests, we evaluated and validated our innovative integrity-based algorithm during field trials on the roads of Nottingham and London.

This project has allowed us to improve MM algorithms and underpins our on-going research which includes:

- the development of an optimisation technique to augment ITS services
- enhancing the algorithm by simultaneously, rather than sequentially, considering all uncertainties
- an objective comparative evaluation of existing integrity methods under the same circumstances to ascertain more robust evidence regarding algorithm performance
- traffic and safety assessments of IM
- advanced IM capabilities for partially and fully autonomous vehicles.

Governance and policy

As we move into the age of intelligent mobility, our lives will be transformed beyond the obvious changes in how we travel and transport goods.

Whilst developing the technologies to underpin future travel, our researchers are also engaged in exploring the social and ethical impacts of IM.

Mobility as service – transport planning in the age of IM

Advances in communication and sensor technologies can support transport systems in which supply and demand are actively managed almost simultaneously.

Thus, the current pre-planned, static, fixed route, provider-led notion of public transport is set to change to a far more responsive, dynamic, flexible route, user-led paradigm – with significant societal benefits.

Our researchers have worked with a variety of partners, including the New Zealand Ministry of Transport, Govia Thameslink Railway, and Highways England to explore the opportunities and challenges for transport presented by evolving technologies and business models.

Work in this area spans the potential of smart-motorways, contactless pay-as-you-go public transport, traffic generator-led transport provision, and dial-a-pod travel.

Whilst some of these aspects of user-centred IM are already existent, others will see a revolution in how we travel and move goods.

For instance, the Mobility as a Service (MaaS) model now being adopted by companies like Uber and Zipcar is beginning to significantly change local travel, and looks likely to become far more widespread.

Meanwhile the potential for seamlessly booking and travelling on journeys provided by multiple operators and using a whole range of transport modes – including, eventually, driverless taxi pods – will soon be realised, providing even more choice in how and when journeys are made.

Similarly, traffic generating organisations such as universities or office developments – may one day routinely communicate the travel needs of their staff, students, visitors and customers directly with MaaS providers, whereby specially developed algorithms would devise a range of tailored transport services to be efficiently delivered with minimal difficulty to travellers leaving the site.

Our researchers are exploring how these new transport technologies and systems could work – improving our daily routines and reducing the environmental impact of our journeys.

Policy

Established in 1972, our Transport Studies Group delivers research that underpins policy and practice worldwide.

As well as supporting the creation of resilient and environmentally efficient surface and air transport, we contribute to initiatives to safeguard critical systems, infrastructures and users from new and evolving challenges and threats.

We have an established portfolio of funded research spanning:

- congestion and traffic-related pollution
- public acceptance of and attitudes towards transport policy
- sustainable aviation
- transport safety and policy
- travel behaviour and traffic demand management.

Our track record for improving transport management and measuring user acceptance of change and innovation underpins partnerships with a range of organisations including BAA, the Commission for Integrated Transport, Defra, Department for Transport, UK local authorities, EUROCONTROL, the Health and Safety Executive and the Highways Agency.

As transport and urban spaces become increasingly connected and autonomous, our work becomes ever more critical.

Our expertise in assessing public acceptance of change – from parking levies to pilotless aircraft – will support the smooth transition from current to future transport systems.

Ethics

The intelligent mobility agenda is changing how we travel and live.

However, the deployment of artificial intelligence as part of this revolution raises a variety of ethical questions. Our experts support various think tanks and legislative bodies across Europe that are leading on the ethical implementation of IM.

For example, we have contributed to the European roadmap and agenda for cyber physical systems (CPS) research, including transport, through leadership of support actions, and have advised the European Parliament on the ethical implications of CPS, especially in the areas of security and defence.

To find out more about how we can work with you to address the challenges of intelligent mobility, please get in touch.

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