Department for Transport

Science Advisory Council Annual Report 2021

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All Science Advisory Council advice, including that reflected in this report, is independent and does not represent the positions of DfT and DfT ministers.

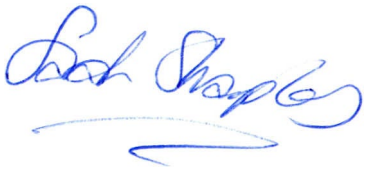
Foreword by DfT Chief Scientific Adviser

Having been a member of the Science Advisory Council (SAC) prior to my appointment as Chief Scientific Adviser (CSA) in July 2021, I joined DfT with an appreciation of the important role that the SAC can play in supporting the CSA and DfT as a whole. The SAC provides insight across the breadth of DfT's areas of responsibility and convenes a wide range of expertise in science, social science and engineering. The SAC adds to the challenge and advice function of the CSA, helps ensure that DfT's science and engineering advice and evidence is robust, relevant and high-quality, and supports horizon scanning to identify emerging areas in science, engineering and technology that may be relevant to transport in the medium- and longer-term.

Understanding, enabling and utilising science and technology is of ever-increasing importance to the delivery of DfT's strategic priorities. Having high-quality evidence and supporting the best innovation is essential to achieving transport decarbonisation, addressing other environmental impacts, and improving the transport system for its diverse range of users. SAC deep-dives on digital twins and science for resilience during 2021 were very helpful in shaping DfT action on these important areas, which are typical of the opportunities and challenges that science and engineering can help address.

I would like to thank those SAC members who stood down in 2021 − Professor Lord Robert Mair, Professor Barry Clarke and Professor Paul Watson. Particular thanks must go to Robert Mair, who departed as chair having held the role since the SAC's creation in 2014. Robert has been an excellent leader of the SAC, and a skilful and inclusive chair, as well as providing considerable support to DfT as an expert adviser on civil engineering matters. His wisdom and advice will be missed.

For the first time, an advertised and fully open campaign was conducted during 2021 to appoint a new chair and members, resulting in a large number and wide range of excellent applicants. The SAC's new chair, Professor Alastair Lewis, brings a wealth of experience in research funding, policy and government engagement, and will be a fantastic addition to the SAC as well as an expert chair. The other five new members are all experts in their fields, as well as offering broader scientific and strategic understanding, and will significantly enhance the diversity of capabilities within the SAC. I look forward to working with them and all members to continue, and further develop, the valuable work of the SAC.



Professor Sarah Sharples FIET FIEHF CErgHF

Foreword by Chair of the Science Advisory Council

I am very pleased to have been appointed SAC chair and have the opportunity to lead a highly distinguished and capable group of members to assist DfT in addressing the very important opportunities and challenges facing transport.

The effective use of science and engineering by government is critical to achieving transport decarbonisation and seizing the huge opportunities of transport innovation to deliver a future transport system that is improved for the user and supports benefits across the economy and society. Close working and dialogue with external expertise and perspectives, such as via the SAC, can help ensure that DfT's plans are well informed and robust. The SAC will also continue to play a valuable role advising and assist on the implementation of the science system within DfT itself, as set out in the Department's Science Plan.

New members appointed to the SAC in 2021 bring significant additional capabilities and skills, enabling the SAC to add value across a wide range of DfT's remit, and to link with an even wider pool of external expertise. I look forward to building on the SAC's past activities and ways of working to further enhance its impact. As we come out of the COVID-19 pandemic the SAC will enjoy returning to meeting in person, and members are enthusiastic to engage more flexibly with teams across DfT and to refresh links with the Department's senior leadership.

I would like to thank all the members of the SAC for their commitment and contributions, and I look forward to working with them further.

Professor Alastair Lewis FRSC

Executive summary

The DfT Science Advisory Council (SAC) provides independent strategic advice and challenge to DfT on a range of science, social science, technology and engineering issues relevant to DfT policy and operations, helping to support the Chief Scientific Adviser (CSA) in ensuring departmental activity is informed by external expertise. SAC members are academic and industry leaders with specialisms relevant to transport.

This report provides an overview of SAC activities during 2021, including summarises of the main topics discussed and key points of advice. All SAC advice, including that reflected in this report, is independent and does not represent the positions of DfT and DfT ministers.

The SAC's membership was substantially refreshed during 2021, with the appointment of a new Chair and five new members via open competition, and with three valued members stepping down.

The SAC met three times during 2021, with meetings held online due to the COVID-19 pandemic. Full minutes of the meetings are provided as annexes to this report. Topics on which the SAC provided significant advice were:

- Digital twins for the transport system
- Science for a resilient transport system

These discussions and input from the SAC were helpful in shaping DfT's subsequent approach and actions on these topics.

1. Introduction to the Science Advisory Council

The DfT Science Advisory Council (SAC) was established in 2014 to provide strategic advice and challenge to DfT on key science and technology areas. The SAC's membership is formed of academic and industry leaders with specialisms relevant to transport. Biographies of members during 2021 are provided in Annex A.

The SAC provides independent expert advice and challenge on a range of science, social science, technology and engineering issues relevant to DfT policy and operations. Members support the Chief Scientific Adviser (CSA) in ensuring departmental activity is informed by the best external expertise and evidence.

Broadly, the specific activities undertaken by the SAC include:

- horizon scanning, identifying opportunities and risks around emerging science and technology relevant to transport, and advising how DfT can best respond
- advising how science and technology can inform and support policy in specific areas
- advising on the quality of science processes and capability within DfT
- strengthening links with industry and the academic community

When examining science and innovation in specific areas, the SAC works with DfT policy leads to identify and frame the issue, and typically consults additional, subject-specific experts to bring new thinking and evidence into DfT.

This annual report provides an overview of SAC activities during 2021, covering membership changes, and outlining of the discussion topics and key recommendations and advice given by the SAC.

2. Membership

During 2021, a new Chair and five new members were appointed to the SAC, with three members stepping down. Appointments were made on merit, based on applicants' knowledge of priority domain areas and wider skills, following an advertised and open process.

Chair

Professor Lord Robert Mair, Emeritus Professor of Civil Engineering at the University of Cambridge, stood down as SAC Chair in September. Professor Lord Mair had held the position since the formation of the SAC in 2014, and achieved a great deal in supporting and advising DfT during that time.

Professor Alastair Lewis, Professor of Atmospheric Chemistry at the University of York, was appointed as the new Chair on a four-year term from December 2021. Professor Lewis has significant experience at the interface between science and policy, including as Chair of the Air Quality Expert Group since 2019, an independent advisory committee to the Department for Environment, Food and Rural Affairs (Defra).

Members

Two other highly-valued members of the SAC stood down during 2021:

- Professor Barry Clarke, Professor of Geotechnical Engineering at the University of Leeds (appointed 2014)
- Professor Paul Watson, Professor of Computer Science at Newcastle University (appointed 2017)

Following receipt of a large number of high-quality applications, five new members were appointed to the SAC for four-year terms commencing December 2021:

- James Gaade, Head of Programme Management, The Faraday Institution
- Dr Siddartha Khastgir, Head of Verification and Validation of Connected and Autonomous Vehicles, WMG, University of Warwick
- Professor William Powrie, Professor of Geotechnical Engineering, University of Southampton

- Dr Emma Taylor, Head of Digital Safety, RazorSecure Ltd
- Professor Patricia Thornley, Director of the Energy & Bioproducts Research Institute, Aston University

These new appointments join six continuing members to provide increased breadth and diversity of expertise, capabilities and perspectives within the SAC, helping ensure that it is able to provide high-quality strategic science and technology advice to the CSA and DfT. This will be maintained through reviewing and refreshing SAC membership every two years.

Annex A contains biographies of all members during 2021.

3. Summary of SAC activity during 2021

The SAC met three times during 2021, with meetings held online due to the COVID-19 pandemic. Minutes of these meetings are provided in Annexes B to D.

At the first two meetings of 2021, the SAC held deep-dives on the following topics:

- Digital twins for the transport system
- Science for a resilient transport system

For each of these areas, the context of the SAC discussion, key points raised by the SAC, and how the SAC's input was used within DfT are summarised below. The SAC were joined by additional subject matter experts from academia, industry and government to contribute their views to these discussions.

The final meeting of 2021, in December, focussed on introducing new members to DfT and each other, and discussing plans for SAC activity in 2022. A summary is provided below.

Digital twins for the transport system − 18 May 2021

A digital twin is a digital representation of a real-world asset, system or process, which has a two-way data flow with its physical twin to monitor, evaluate and optimise the physical asset over its lifecycle. The opportunity and value of a coordinated national approach on digital twins for the UK's infrastructure was highlighted in the National Infrastructure Commission's 2017 report Data for the Public Good, and recommendations from this report are being delivered through the National Digital Twin Programme. The SAC were challenged with discussing how DfT and others in the transport sector identify the opportunities of digital twins and integrate the transport sector needs with this wider activity.

The SAC and additional attendees discussed the key opportunities of digital twins for the transport system, and what is needed from DfT and wider government to realise them. The discussion focused on opportunities to apply digital twins at the scale of the transport system itself, rather than for individual products, such as vehicles.

The SAC concluded that:

- DfT can play an important role in providing guidance and coordinating activity on digital twins across its arm's length bodies and the wider transport sector, and in shaping the development of the National Digital Twin Programme to support transport.
- It remains a key challenge for researchers and government to demonstrate the practicalities and business models for commercial organisations to readily share their data.
- Connected digital twins and sharing of data creates complex issues around ownership, liability, trust, regulation and auditing, and these will need to be understood and suitable approaches taken.
- Embedding the skills needed for digital twins and similar technology within the transport sector will be a challenge, and government can play an important role here.

The conclusions from the SAC discussion fed into further activity by the Transport Research and Innovation Board (TRIB) to highlight the opportunity and academic challenges of digital twins for transport, and to coordinate activity and engagement across the sector. This included working with DfT's arm's length bodies, the Department for Business, Energy and Industrial Strategy (BEIS) and UK Research and Innovation (UKRI) to identify priority use cases, and resulted in research into digital twinning for the decarbonisation of transport being identified as a priority for potential funding.

Minutes of this discussion are provided in Annex B.

Science for a resilient transport system − 28 September 2021

The UK transport system is critical to society, our economy and prosperity, and it is essential our networks are resilient to a wide range of risks. There is a sustained threat from terrorism, continued risk from unintended hazards such as severe weather exacerbated by climate change, and increased risks associated with reliance on critical system technologies. The COVID-19 pandemic also interrupted the normal operation of much of the transport network, and learnings from this are relevant to understanding both the delivery of a transport system able to function safely under a potential future pandemic, and to wider resilience. Science and technology have an increasingly important role to play in supporting DfT decision making, driving innovation and the rapid delivery of new solutions and technologies to mitigate transport risks.

The SAC was asked to assist DfT in identifying approaches and opportunities for effective use of science and technology to support the design, delivery and operation of a resilient transport system, able to function under such disruptive scenarios. The SAC were joined by DfT colleagues and external experts, and heard case studies on the Met Office’s programme on science for climate resilience, and work by the Royal Academy of Engineering on approaches to delivering infection resilient environments.

The SAC identified as key themes:

- the importance of effective partnership working across disciplines and perspectives, including scientists, operators and users, to understanding complex risks and possible unintended consequences, and the value of sharing a common language around risk and resilience

- the value of a systems approach to identify interdependencies between multiple risks and with other policy priorities such as net-zero
- the opportunities provided by smart-sensing monitoring and data science to support continuous learning about complex systems, enabling us to better adapt and respond to events
- the importance of social and behavioural aspects of resilience, including understanding behaviours and public preparedness

The SAC discussion assisted in the prioritisation of DfT's science and technology investment in resilience, including informing evidence and research priorities for 2022-23. This included the development of the Science and Technology Advice for Risks and Resilience (STARR) programme, with the purpose of reducing the impact of civil contingencies and natural hazards on UK transport users by informing and improving risk assessment, preparedness, mitigation and response through the application of science and technology

Minutes of this discussion are provided in Annex C.

New members and forward planning − 15 December 2021

The December meeting was the first with Professor Alastair Lewis as Chair and with five other new SAC members. Introductions from members, summarising their areas of expertise, gave a clear demonstration of the expanded breadth of knowledge and skills available within the SAC.

Continuing members led an item reviewing the operation of the SAC, to identify good practice, challenges and potential areas for improvement or evolution. Members were keen to re-energise dialogue with DfT's senior leaders, and to support teams across DfT more directly through regular engagement of individual SAC members and sub-groups, and as an access route to an even wider list of external experts. These aims will be taken forward in 2022.

Presentations from members on emerging, strategic science or engineering topics fed into the identification of several high-level priority themes for potential SAC work in 2022. These included:

- Future fuels
- "Secure by design" transport
- Systems approach to decarbonisation
- Re-imagining travel and communities

It was agreed that SAC deep-dive topics should continue to include both emerging issues identified by SAC members and areas requested by DfT in response to specific needs.

Minutes of this meeting are provided in Annex D.

Annex A: Member biographies

Membership at the end of 2021

Chair, Professor Alastair Lewis FRSC

Alastair Lewis is currently Professor of Atmospheric Chemistry at the University of York and a Science Director at the National Centre for Atmospheric Science.

Professor Lewis is an experimentalist who studies atmospheric emissions and the wider impacts of air pollution on ecosystems, climate and public health. His research has included making field measurements of pollution on all seven continents, from onboard ships and from research aircraft. He has developed new methods of chemical analysis that have illuminated the roles that fuels and combustion play in atmospheric processes, from city centres to the global scale.

Professor Lewis has been awarded the Royal Society of Chemistry John Jeyes Prize for Environment, Energy and Sustainability and its Silver Medal for Analytical Science, along with a Philip Leverhulme Prize in Earth, Ocean and Atmospheric Sciences. He has authored more than 300 academic papers, reviews and reports.

Professor Lewis has been chair of the Air Quality Expert Group since 2019, an independent advisory committee to the Department for Environment, Food and Rural Affairs (DEFRA).

Previous roles have included a 5-year part-time secondment with the Natural Environment Research Council developing investment strategies for technology development and working with science advisory boards for several UK research councils, the World Meteorological Organisation and UN-Environment. He has served on the chemistry subpanel for both the 2014 and 2021 Research Excellence Framework assessments.

Anna-Marie Greenaway MEI

Anna-Marie Greenaway is currently completing a PhD at the University of Cambridge, following a 30-year career in international energy. Her PhD is exploring the development of strategic road-mapping frameworks and toolkits to support delivery of net zero carbon ambitions.

Until September 2020, she was Global Director of International University Partnerships at BP. This role encompassed developing and leading BP's strategy for technical and policy research collaborations worldwide including on climate change, alternative energies, transport systems and carbon sequestration.

From 2015 to 2020, she served on the governance boards of the BP Institute and the International Centre for Advanced Materials and the advisory committees of the Cambridge Centre for Risk Studies, Scott Polar Research Institute and the Clean Energy Centre at Tsinghua University, Beijing.

Previously, Anna-Marie spent 4 years in BP's Group Strategy team, where she led the 2030 Low Carbon Energy Pathways research programme, covering the UK, US, EU, China, India and Brazil. This involved bringing multidisciplinary BP teams together with external partners from wider industry sectors, government bodies and leading academics.

Her academic background is in earth sciences and she holds a BSc from Royal Holloway, University of London and a master's degree in Sustainability Leadership from the University of Cambridge.

Dr Dave Smith FIET FRAeS

Dave is the Director of Central Technology and Strategy within the Innovation Hub of Rolls-Royce. He leads a team providing new technological and business concepts, disruptive technologies, management of the group innovation culture and the global university network, as well as heading up the net zero strategy for Rolls-Royce. He is additionally Director of Rolls-Royce Civil Nuclear UK.

Before joining Rolls-Royce in 2017, Dave was Managing Director of the Ricardo Automotive Engineering Consulting businesses, comprising companies throughout Europe and with sales teams in Japan, India and Korea.

Previously, he was Global Head of PA Consulting's technology consulting, product development and innovation business and Managing Director of Roke Manor, the communications and software research and development (R&D) company, which received the Queen's Award for Innovation. He sat on the Global Research Committee for Siemens AG.

Dave holds a PhD in physics from the University of Warwick and is a member of the Institution of Engineering and Technology Policy Panel on Innovation and Emerging Technologies. He sits on many advisory boards in the UK and Singapore.

Dr Emma Taylor CEng FIMechE FSaRS FRAS FRSA

Dr Emma Taylor is Head of Digital Safety at RazorSecure, which provides cyber security solutions for rail.

She is a Chartered Engineer with 30 years' experience in academia and industry across different highly regulated sectors including transport and space. She led the development of an ISO standard for space sector environmental mitigation and is part of

the CENELEC rail cyber security group. A visiting professor at Cranfield University, working within Aerospace, Transport and Manufacturing, she is also a past chair of the Safety and Reliability Society.

Emma was previously a Lead System Safety Engineer at RSSB, where she led risk evaluation of operational changes. Emma also led industry-wide engagement with poorly understood hazards associated with complex software-based systems following recommendations made by the Rail Accident Investigation Branch. She is now developing the framework for data standards for digital accident investigation, engaging across multiple critical national infrastructure sectors to support transport sustainability, resilience and recovery.

Previously recognised through a number of awards including Telegraph Top 50 Women in Engineering, Cranfield University School of Management, Financial Times Top 100 Most Influential Women in UK Engineering and Computer Weekly's Top 50 Women in Tech, Emma encourages and mentors underrepresented groups in technical careers.

Emma received her degree in physics from the University of Oxford in 1993, her PhD in 1998, and has 2 master's degrees, in Space Science and Safety Engineering.

James Gaade FIMechE CEng

James Gaade is Head of Programme Management at The Faraday Institution, the UK's independent institute for electrochemical energy storage research, skills development, market analysis and early stage commercialisation. James has responsibilities across the research programme portfolio, bringing together research scientists and industry partners on battery research projects with commercial potential.

Prior to joining The Faraday Institution, James led an independent consultancy, working with the UK Battery Industrialisation Centre on developing supply chain capability for battery materials, with the British Standards Institute as technical author of a code of practice for battery modules and packs, with SMEs on collaborative technology projects and supporting the Advanced Propulsion Centre Technology Developer Accelerator Programme.

Previously, James worked for Jaguar Land Rover for 20 years on vehicle propulsion systems, working on projects from research through to vehicle production. He held varied leadership roles in product engineering, research and technology and product marketing. James's last role was Head of Powertrain Research and Technology, where he led a team of engineers delivering a research portfolio focused on the next generation of vehicle electrification technologies and internal combustion engine capability for near-zero emissions, working collaboratively with industry and academic partners.

A Chartered Engineer and Fellow of the Institute of Mechanical Engineering, James graduated from De Montfort University with a BEng in Mechanical Engineering and from Loughborough University with an MSc in Automotive Systems Engineering.

Professor Nick Pidgeon MBE

Nick is Professor of Environmental Risk and Director of the Understanding Risk Research Group within the School of Psychology at Cardiff University. His research and science policy work is interdisciplinary, at the interface of social psychology, human geography, risk research and the sociology of technologies.

He has worked over the years on safety and the organisational causes of major industrial accidents, on monetary and non-monetary valuation of risk and safety, and latterly on how the public view and engage with environmental and technological risks and sustainability.

His most recent work has focused on topics such as attitudes to nuclear power and renewable energy, people's biographies of everyday energy use including that of transportation, attitudes to future energy-system change, and perceptions of climate change risk. He is currently a co-investigator to the UK Energy Research Centre.

Professor Pidgeon has filled numerous science advisory roles, including for Her Majesty's Treasury (HMT), DEFRA, the former Department of Energy and Climate Change, the National Infrastructure Commission and the former National Radiological Protection Board.

He is a Fellow of the Society for Risk Analysis, an Honorary Fellow of the British Science Association and was awarded an MBE in 2014 for services to climate change awareness and energy security policy.

In 2006, he chaired the All-Party Parliamentary Group on Climate Change inquiry, which recommended the setting up of the UK Climate Change Committee.

Before moving to Cardiff in 2006, Nick directed the Centre for Environmental Risk at the School of Environmental Sciences at the University of East Anglia. Before that, he held positions at Bangor University and at Birkbeck College, University of London.

Professor Patricia Thornley FREng

Patricia Thornley is a fellow of the Royal Academy of Engineering with 28 years' experience working on energy projects in industry and academia. She is director of the Energy and Bioproducts Research Institute at Aston University and Associate Dean for Research at Aston's College of Engineering and Physical Sciences.

Patricia has led the UK's £6 million SUPERGEN Bioenergy hub since 2012, with responsibility for coordinating research into bioenergy and strategically guiding its membership of over 30 academic and 20 industrial and policy partners to focus on sustainable bioenergy and biofuel development.

Patricia's research focuses on sustainability assessment of energy systems, particularly bioenergy and low carbon fuels, evaluating the environmental, economic and social consequences of implementation pathways.

Working at the interface of the academic, policy and industrial communities, she served as an expert in the 2020 Climate Assembly UK, a member of the advisory group for Elsevier's

2021 international report on pathways to net zero, and chaired the Climate Change Committee's advisory board for its 2020 biomass report.

Currently, Patricia is a member of the Energy Working Group supporting HMT's Green Technical Advisory Group, DEFRA's Tree and Woodland Scientific Advisory Group and the National Farmers' Union Net Zero Advisory Board.

Professor Peter Jones OBE FCIHT FRGS HonFIHE

Peter Jones is Professor of Transport and Sustainable Development in the Centre for Transport Studies at University College London (UCL).

He is a member of the Independent Transport Commission, the City of London Transport Strategy Board, the South-East Wales Transport Commission, the Dubai Council for Future Transportation, the Hong Kong ERP Advisory Panel and the Chartered Institution of Highways and Transportation Urban Design Panel.

As well as his membership of DfT's Science Advisory Council, Professor Jones co-chairs the DfT's Joint Analysis Development Panel.

Professor Jones advises the European Commission and a number of major cities and national governments around the world and was awarded an OBE for services to national transport policy in January 2017.

He is involved in a number of national and international research projects, including being Scientific Co-ordinator of the EU 'MORE' project, which is looking at future pressures on main roads in cities resulting from socio-demographic changes and technological developments, and how these might be accommodated through more dynamic allocation of road space.

He also plays a leading role in representing UCL on the EIT for Urban Mobility, an EU Knowledge Innovation Community established in 2019.

Professor Jones has a wide range of transport research and teaching interests, covering analytical methods and policy, including:

- traveller attitudes and behaviour
- travel trends and the determinants of travel demand
- traffic restraint studies
- accessibility studies
- policy option generation
- major transport economic and social impact studies
- public engagement
- development of new survey and appraisal methods
- activity-based modelling and analysis
- advances in urban street planning and design

Professor Ricardo Martinez-Botas FREng

Ricardo is Professor of Turbomachinery and Deputy Head of the Department of Mechanical Engineering at Imperial College London.

He leads a research group in the area of low carbon vehicles with particular emphasis on highly downsized engines, turbochargers and energy storage systems. He has developed the area of unsteady flow aerodynamics of small turbines, with particular application to the turbocharger industry.

Ricardo's collaborations with international engine, turbocharger and vehicle companies have led to ground-breaking technical innovation and industrial impact. He directs 2 University Technology Centres at Imperial College: The Caterpillar Innovation and Research Centre and The Mitsubishi Heavy Industries (MHIET) Future of Boosting Innovation Centre. These bring researchers together with world-leading industrial partners, to take science and innovation through to having real-world impact.

From 2020 to 2021 Ricardo was Chair of the ASME International Gas Turbine Institute. He is a visiting professor at the University Teknologi of Malaysia and a guest professor at Shanghai Jiatong University. He has published over 120 journal papers, has contributed to many peer-reviewed conferences and is an associate editor of 2 journals.

Ricardo has an MEng degree in Aeronautical Engineering from Imperial College London and a DPhil from the University of Oxford. In 2019, he was awarded the President's Medal for Excellence in Research by Imperial College.

Professor Rob Miller FREng

Rob is Chair in Aerothermal Technology and Director of the Whittle Laboratory for turbomachinery research at the University of Cambridge. His research is aimed at reducing the emissions of both air travel and land-based power production, on which he works with a multidisciplinary team and a range of leading companies.

Professor Miller's research interests include compressors and turbine aerodynamics, effects of manufacturing variation, pressure gain combustion for gas turbines, and energy and the environment.

Professor Miller has won the American Society of Mechanical Engineers Gas Turbine Award 3 times and the Institution of Mechanical Engineers Thomas Hawksley Gold Medal in 2010.

Before joining the University of Cambridge in 2001, he was a Senior Lecturer at New College, Oxford University, and obtained his DPhil from Oxford.

Dr Siddartha Khastgir CEng MIMechE

Siddartha Khastgir is the Head of Verification and Validation for Connected and Autonomous Vehicles (CAVs) at WMG, University of Warwick. He leads several

collaborative R&D projects with industrial and academic partners nationally and internationally.

Siddartha's research focuses on generating safety evidence and arguments, test scenario generation, simulation-based testing and safety of AI systems. Leveraging the cross-domain nature of safety, he is also involved in safety research in aviation, marine and healthcare.

Siddartha is an active member of various national and international standardisation and regulatory groups, including ISO, SAE and ASAM. Currently, he represents the UK on several ISO technical committees and is the lead author for 2 new ISO standards for aspects of automated driving systems. He sits on the United Nations Economic Commission for Europe committees on safety of automated driving.

Prior to joining WMG, Siddartha was with FEV GmbH in Germany, leading automotive software development and testing for series production projects.

Siddartha has received national and international recognition for his research contributions, including the prestigious UKRI Future Leaders Fellowship in 2019 focused on safety evaluation of CAVs, and was listed as one of Forbes 30 Under 30 Europe 2018. He is an active public speaker, including giving a TEDx talk on his research on the safety of CAVs.

Siddartha is a Chartered Engineer and an elected member of the Institution of Mechanical Engineers Council. He holds a degree in Mechanical Engineering from the Indian Institute of Technology Kharagpur and a PhD from WMG, University of Warwick.

Professor William Powrie FREng CEng FICE

William is Professor of Geotechnical Engineering and former Dean of Engineering and the Environment at the University of Southampton. He has long-standing research and educational interests in transportation infrastructure, including impacts on and of the environment and the wider role of transport in society.

William is Convenor of the UK Collaboratorium for Research on Infrastructure and Cities (UKCRIC) and leads the UK Rail Research and Innovation Network (UKRRIN) Centre of Excellence in Infrastructure. He is a Fellow of the Royal Academy of Engineering, the Institution of Civil Engineers and the Permanent Way Institution.

Through his research, William has been involved in major transportation infrastructure projects including the North Wales Coast Road Conwy Crossing, the Medway Tunnel, Jubilee Line Extension stations at Canary Wharf and Canada Water, the Thames Tunnel and embedded retaining walls on HS1. Recent research for Network Rail led to a substantial reduction in the cost of railway electrification mast foundations, following previous cost overruns in this area.

William currently chairs HS2's Geotechnical Independent Expert Panel and the Royal Academy of Engineering / Lloyds Register Foundation, Engineering X, Safer End of Engineered Life Programme Board.

Members who stepped down during 2021

Chair, Professor Lord (Robert) Mair CBE FREng FICE FRS

Professor Lord Mair is Emeritus Professor of Civil Engineering and former Head of Civil Engineering at Cambridge University. He was President of the Institution of Civil Engineers from 2017 to 2018, Senior Vice-President of the Royal Academy of Engineering from 2008 to 2011 and elected to the US National Academy of Engineering in 2019.

He was elected a Fellow of the Royal Society in 2007 and awarded the CBE in 2010 for services to Engineering. In 2015 he was appointed an independent crossbencher in the House of Lords, where he is a member of the Risk Assessment and Risk Planning Committee, and a former member of the Science and Technology Committee.

Professor Lord Mair was appointed Professor of Geotechnical Engineering at Cambridge in 1998. He was the Sir Kirby Laing Professor of Civil Engineering from 2011 to 2017 and Master of Jesus College from 2001 to 2011.

Before his professorship at Cambridge, he worked in industry for 27 years: in 1983 founding the Geotechnical Consulting Group, an international consulting company based in London. He is Engineering Adviser to the Laing O'Rourke Group.

His research group at Cambridge specialises in the geotechnics of tunnelling and underground construction. He has advised on numerous tunnelling and major civil engineering projects in the UK and worldwide, including the Jubilee Line Extension project for London Underground, Crossrail and HS2.

He introduced the technique of compensation grouting to the UK. This was successfully used to protect Big Ben from movement due to the construction of the adjacent Westminster Station and the technique has now been adopted worldwide.

He was closely involved with Crossrail, Europe's largest civil engineering project, and was a member of its Engineering Expert Panel.

Professor Lord Mair also leads the Centre for Smart Infrastructure and Construction (CSIC) at Cambridge, involving the innovative use of the latest sensor technologies to monitor the behaviour and performance of civil engineering infrastructure. He chaired the Royal Society/Royal Academy of Engineering report on shale gas for the government, published in 2012 and the Task Force Review of Network Rail's Management of Earthworks following the tragic train derailment in Scotland in 2020.

Professor Barry Clarke FICE FGS CEng

Barry Clarke is Professor of Civil Engineering Geotechnics and a founding director of the Institute of Resilient Infrastructure at the University of Leeds. He's a past president of both the Institution of Civil Engineers (2012 to 2013) and the UK Engineering Professors Council.

He's currently a member of the governing body of the International Engineering Alliance, the Engineering Council UK International Advisory Panel, and is a founding member of the UK Collaboratorium for Research in Infrastructure and Cities (UKCRIC).

His former national roles include Chair of the UK Engineering Accreditation Board, President of the UK Engineering Professors Council, Chair of the British Geotechnical Association, Chair of UK Ground Forum, and Head of Civil Engineering at Newcastle University.

He was a member of the Board of CITB-Construction Skills, the Construction Industry Council Executive, and EPSRC's Strategic Advisory Teams for Process, Environment and Sustainability, and Engineering.

Professor Clarke is a civil engineer with interests in the role of engineering in society, the education of engineers, characterisation of ground, application of electrokinetics in groundworks, ground as a source of energy, engineering in complex soils and the application of artificial intelligence in construction practice. He's been retained as an expert witness and advisor to the construction industry on a variety of major projects.

He has helped form 2 spin-out companies from his research in ground characterisation and electrokinetics. He's currently involved in the use of artificial intelligence in the installation and management of utility networks and engineering in complex ground conditions.

Professor Paul Watson FREng

Paul Watson is Professor of Computer Science and Director of the Digital Institute at Newcastle University. He is a Fellow of the Alan Turing Institute and Principal Investigator of the EPSRC Centre for Doctoral Training in Cloud Computing for Big Data.

Before this, he directed the Digital Economy Hub on Social Inclusion through the Digital Economy, which focused on using advanced computing technologies to transform the lives of older people and those with disabilities.

Paul graduated from Manchester University with a BSc in Computer Engineering in 1983, followed by a PhD on parallel computing in 1986.

In the 1980s, as a Lecturer at Manchester University, he was a designer of the Alvey Flagship and Esprit EDS systems. From 1990 to 1995 he worked for ICL as a system designer of their Goldrush MegaServer parallel database server.

In 1995 he moved to Newcastle University, where he has led a range of research projects. His research interest is in scalable information management with a current focus on data analytics and IoT. He also sits on the board of Dynamo North East, an industry-led organisation created to grow the IT economy of the region.

Professor Watson is a Fellow of the Royal Academy of Engineering, a Fellow of the British Computer Society, a Chartered Engineer and a member of the UK Computing Research Committee. He received the 2014 Jim Gray eScience Award.

Annex B: 18 May 2021 meeting minutes - Digital twins for the transport system

These minutes summarise the range of independent views and opinions expressed during the meeting, without generally attributing these to individual attendees. Individual opinions may not be the view of the SAC or group of attendees as a whole. Neither individual views nor SAC advice should be taken as representing the positions of DfT and DfT ministers.

DfT Science Advisory Council

11:30–16:00 Tuesday 18 May 2021

Via videoconference

Council members attending

- Professor Lord Robert Mair, Chair
- Anna-Marie Greenaway
- Professor Barry Clarke
- Dr Dave Smith
- Professor Nick Pidgeon
- Professor Paul Watson
- Professor Peter Jones
- Professor Ricardo Martinez-Botas
- Professor Rob Miller
- Professor Sarah Sharples

DfT attendees

- Professor Phil Blythe, Chief Scientific Adviser
- Dr Siobhan Campbell, Head of Central Research Team
- Head of Science and Innovation Delivery – Office for Science
- Head of Science Strategy – Office for Science

- Private Secretary to the Chief Scientific Adviser
- SAC Secretariat

Additional participants for item 5 only

- Head of Futures, Office for Science, DfT

Additional participants for item 6 only

- Davin Crowley-Sweet, Chief Data Officer, Highways England
- Dr Kedar Pandya, Director for Cross-Council Programmes, EPSRC
- Luisa Moisio, Director of Research and Development, Rail Safety and Standards Board
- Mark Enzer, Digital Director, Centre for Digital Built Britain / Chief Technology Officer, Mott MacDonald
- Mark Lyons, Chief Technology Officer, DfT
- Mike Waters, Director of Policy, Strategy and Innovation, Transport for the West Midlands
- Professor Phil James, Professor of Urban Data, Newcastle University
- Dr Ron Oren, Digital Twins lead, Connected Places Catapult
- Head of Digital & Data Transformation – Infrastructure and Construction, BEIS
- Head of Data Policy, DfT
- Head of Transport Research and Innovation Board, DfT
- Senior Adviser, Traffic and Technology, DfT

Apologies

None

1. Welcome and introduction

1.1 The Chair and members congratulated Sarah Sharples on her appointment as DfT's new Chief Scientific Adviser.

1.2 As previously notified to members, the Chair confirmed that he will be stepping down from the role after the September meeting.

1.3 Paul Watson was also stepping down from the Council, and this was his final meeting. On behalf of the SAC the Chair thanked him for his valuable contributions since his appointment in 2017. Paul thanked members and reflected that he had learnt a lot and enjoyed the experience.

2. Review of November meeting minutes

2.1 The minutes of the November meeting were agreed without amendments.

2.2 The Secretariat noted that a summary of the key points from the item on capital carbon in infrastructure had also been provided to relevant colleagues within DfT.

3. Chief Scientific Adviser's update and reflections

3.1 The CSA, Phil Blythe, gave an update on current science activity in DfT, including the recently established Research & Development Board, the progression of the DfT Science Plan and Areas of Research Interest, and his involvement with the cross-government Emerging Technologies Board. Following the November SAC, the Transport Research and Innovation Board and others within DfT have continued work to address whole-life carbon in infrastructure. He and officials are continuing to engage with the Scientific Advisory Group for Emergencies (SAGE) and advise ministers on matters related to COVID-19.

3.2 Phil reflected on his six years as CSA, the increasing prominence of science within DfT during that time, and the development of the SAC's role in supporting that. Key moments on this journey have included: DfT's response to the automotive emission testing scandal; shaping the government's Future of Mobility Foresight Study and Grand Challenge within the Industrial Strategy; the government's Science Capability Review; and the response to COVID-19. The department has increased its engagement with external science, including through more inward secondments from academia and industry, and now provides greater coordination on R&D across DfT's arm's length bodies. In the future, it will be important for DfT to continue to focus on climate change, resilience issues, and accessible transport for all.

3.3 As incoming CSA, Sarah Sharples thanked Phil for all he has done in the role, and the SAC for their support. She highlighted the importance of DfT ensuring value from UKRI investments; the government's new Advanced Research and Invention Agency; and the need to develop resilient transport systems that are also innovative.

3.4 The Chair thanked Phil on behalf of the SAC for all that he has achieved as CSA, and said that it has been a pleasure working closely with him over the last six years on developing the SAC and its activities.

4. SAC membership refresh

4.1 Members made the following comments on the planned process for appointing new SAC members ahead of the September meeting:

- Overall timings seem tight, given the need to publicise and encourage candidates to apply. Members felt three weeks was too short for applications to be open, and that candidates may be less easy to engage over the summer months.
- Mapping of skills and gaps needs to be done quickly. Current members should be asked to provide their skills and expertise, rather than this being done on their behalf.
- Publicising the opportunity should include actively encouraging suitable candidates to apply. Some of the reflections from Phil and Sarah in the previous item could be developed into a persuasive message on the value of contributing to the SAC.
- We should be clear about the desired balance between academia and industry on the SAC, and communicate this explicitly to encourage industry candidates. Industry bodies should be used to help engage industry candidates.

- Thought and effort needs to be put into addressing diversity, including careful wording of the advert.
- Members supported having a standard term for membership with the possibility of extension.

4.2 Members had the following comments on the prioritisation of skills/expertise for recruitment:

- There is an immediate need for data and digital expertise following the departure of Paul Watson and, before him, Paul Newman.
- Some coverage of accessible and age-friendly transport would be desirable.
- Someone with direct experience of operational delivery of the transport system, e.g. network management, would bring a useful different perspective
- Someone who can represent considerations around the natural environment, including environmental impacts, climate adaptation and resilience, would add value.
- Cycling, walking and micromobility should also be considered when thinking about coverage across transport modes.
- Road transportation remains fundamental to DfT, but its representation on the SAC has reduced over time, so could be increased. The SAC should maintain deep engineering expertise of devices, including vehicles.
- Someone with perspective on the mechanisms and motivations for attracting private finance to transport innovation could be useful.
- An international perspective remains important.
- A distinction should be made between core skills required on the SAC and those that may be more appropriate for a wider pool that the SAC can call upon when required. A wider group of subsidiary SAC members could assist with increasing diversity of representation and perspectives.

5. Space-based technology

5.1 A summary was given of the item paper and the questions to the SAC on the transport applications, opportunities and risks offered by satellite systems.

5.2 SAC members raised the following points:

- There is significant potential application of satellites for safety monitoring of transport networks, including earthwork management. Such monitoring is important for both safety and efficient spending on network management. This was addressed in Robert Mair's recent review of Network Rail's earthworks management.
- Transport can learn from monitoring applications in other sectors that are based on tracking the location of high-value assets or positioning things more accurately than achievable with GPS.
- Low earth orbit satellites could provide a substantial improvement in the accuracy with which aircraft are tracked over oceans. Better positioning enables aircraft to fly closer together on optimum flight paths for fuel efficiency and contrail management. Contrails are a significant contributor to the climate impacts of aviation, and there is a large opportunity to reduce this through contrail management. Partial UK Government ownership of OneWeb provides the UK with an opportunity to take a lead in this application and others.

- There may be relevance to the Industrial Strategy Future of Flight programme, in terms of the future management of large numbers of smaller and unmanned aircraft.
- Multi-modal applications for cities may be more significant than the item paper suggested.
- COVID-19 may increase people's desire to have advance knowledge of how busy a service or location is, and this technology could be relevant to that, as well as to flexible, demand-based charging models.
- When thinking about applications and their resilience, it is important to be clear whether the satellite is providing a critical core service or an enhancement. Similarly, it is important to understand how critically reliant our transport system currently is upon conventional satellite technology, which could be impacted by risks including space weather.
- It is important to be clear if and where this technology offers something additional to other telecommunications, such as GPS and 5G. Linked to this is the major issue of UK access to GPS systems. It should also be asked what new satellite-based technology adds in the eyes of the user, and its effect on trust in data-driven systems.
- Limitations of communications latency (lag) and line of sight requirements will likely make low earth orbit satellites unsuitable for many applications, such as providing services to connected and autonomous vehicles. Some of the strongest use cases may be in maritime and aviation, where these limitations are less of an issue and other services are absent.
- Assessments of the market attractiveness of different use cases should be guided by the views of private sector investors.
- Government has a role in addressing privacy issues and ensuring that provision of services from private providers is inclusive and consistent with the UK's values.

5.3 In the discussion of resilience applications, it was suggested that resilience is often talked about in vague terms, and that at a future meeting the SAC might consider what is practically meant by transport resilience.

6. Digital twins for the transport system

6.1 The Chair welcomed attendees for this item and noted the background paper provided in advance to frame the discussion.

6.2 A presentation was given on the current National Digital Twin Programme, including the following points:

- Digital twins offer value by enabling better decisions, faster.
- It is not the role of the programme to build a national digital twin, but to enable a market that will do this for us, by providing a common information management framework.
- As for their physical counterparts, digital twins need to operate as systems-of-systems, with connected digital twins sharing data. Data needs to be shared across organisational and sector boundaries, and this requires common technical principles and frameworks, as well as shared values.
- The current National Digital Twin Programme is focused on the built environment but is very relevant to transport. Several transport organisations, including Network Rail, East West Rail, Highways England, Transport for London and Heathrow are

conducting early work on digital twins, but are not yet taking a coordinated approach or adopting shared standards.

6.3 There was then a presentation on plans for future development of the National Digital Twin Programme:

- UKRI, working closely with BEIS, has engaged across government to develop its thinking and to inform its investment plans related to digital twins. UKRI is considering how it can play its part in enabling the development of a future national capability involving the next generation of digital twins with desirable characteristics, the integration of those digital twins within and across sectors, and an increase in their adoption and commercialisation.
- The thing that will not be delivered without government intervention – the market failure – is the maximisation of value and benefits to the public. UKRI seeks to provide the enablers to achieve this.
- This SAC discussion was a valuable part of EPSRC's engagement in thinking about transport use cases relevant to the potential programme.

6.4 The following points were discussed in response to the two presentations:

- It was questioned whether there is a need to certify digital twins to ensure they behave as expected when connected to other digital twins. In response, it was suggested that initial connections between digital twins would likely be the exchange of data rather than any control signals, limiting risks. Data quality is critical, and it is generally more important to certify the data quality rather than the digital twins themselves.
- Many people claim to have a digital twin when it may not meet strict definitions of one. The National Digital Twin Programme is finding it more useful to describe digital twins and their variations well, and takes an inclusive approach, rather than adopting strict definitions.
- A coordinated approach between transport players requires regulatory, commercial and legal standards. Accessing the necessary data is often a big challenge. Soft standards and frameworks are also as important as technical aspects, and this requires a socio-technical approach.
- A closed-loop digital twin, without a human involved in deciding interventions, will be appropriate in some cases. In others, a human will be in the loop.

6.5 A presentation was given on the opportunities for digital twins in transport, which included the following views:

- Some of the attributes and benefits of digital twins include intuitive analysis, predictive analytics, parallel running of multiple scenarios, and providing a secure, low-risk, lower-cost environment for testing.
- In terms of the definition of a digital twin, it was argued that it should be able to ingest data sets in near real time, even if it does not trigger an intervention immediately.
- It is important for security to be able to separate insights from underpinning data, and to be able to temporarily decouple the digital twin from its physical counterpart for testing work.
- Digital twins can support incident response by enabling rapid analysis of complex systems, taking account of knock-on effects from mitigation options.

- Digital twins are very relevant to future air mobility applications. Increased use of small and autonomous aircraft will require the management of entirely new and complex systems, and high levels and density of use to be economically viable. This is perfect for the application of digital twins.
- Digital twins are a very logical complement to living labs, and can provide additional insight and learning.
- Foundational requirements include: creating a foundation data model for transport data (a Transport Information Management Framework); improving the accessibility of transport data and supporting the adoption of good data management practice; and improving the data literacy of decision-makers in the sector.
- Visionary opportunities include: multimodal digital twins giving a multimodal view of transport flows and demand; a digital twin of transport flow within and around a multimodal hub such as a port or airport; cross-sector digital twins capturing energy and environmental impacts of transport; and digital twins complementing transport living labs to enable faster experimentation and scale-up of benefits.
- As potential next-steps, it was suggested that DfT could: engage with the National Digital Twin Programme's Climate REsilience DemOnstrator (CReDo) project to add a transport "layer" to its COP26 demonstrator; prioritise transport use cases for (national) digital twin investment; improve data literacy and maturity in the transport sector; and review procurement to facilitate engagement with innovative SMEs in this area.

6.6 A presentation was given on Transport for the West Midlands' (TfWM) current programme on digital twins, which included the following points and views:

- Overall, local authorities do not have the data to enable the best, intelligence-based decision making, and digital twins are part of the solution to this.
- Digital twins offer many opportunities to local authorities for strategic planning of the network, incident response, and enabling of digital user services such as payment platforms.
- The first step is acquiring and managing the data, and TfWM are developing sensor networks including harvesting data from connected vehicles. TfWM find it a challenge accessing and working with national transport data sets.
- Through their Future Transport Zone activity, TfWM are working with DfT on the digitisation of road regulations which will be needed for the future operation of connected and autonomous vehicles.
- It is important to keep the user at the centre of the issue, and there is a need to better understand people's perceptions and emotions affecting demand for services.
- It was suggested that DfT could direct Highways England to play a more collegiate role in working with others to support the digitisation of the road network. They are the key player who can bring this together for roads.
- DfT could accelerate supporting activities, such as the Enabling Connected Autonomous Vehicle Environments (E-CAVE) project, funded by the Industrial Strategy Challenge Fund.

6.7 Attendees were asked to address the questions identified in the background paper:

- What are the key opportunities (and any risks) of digital twins for design and delivery of the transport system? In terms of time, what is the potential proximity to realising these opportunities?

- What is needed (both technical and strategic) to realise these opportunities, and what role should DfT, specifically, play in enabling this?
- What investments and developments in other sectors could transport leverage and/or learn from?

6.8 In response to these questions, and the presentations given, a range of independent views were contributed by SAC members and other invited attendees. In relation to the first question listed under 6.7, on opportunities and timescales, the following points were made:

- Digital twins are not always the answer; better decisions are the answer, and good use of data can provide this, sometimes involving digital twins.
- Use of digital twins needs to be problem- and customer-driven. DfT could consider if and where digital twins could support priorities such as improving transport for the users or decarbonisation.
- It should be remembered that a digital twin does not have to replicate all aspects of a physical system, and need only model the elements that are needed for its purpose, which can potentially limit costs and effort.
- Airport operations were suggested as a natural use case, and it was questioned whether any had yet demonstrated a compelling business case that might be used as an exemplar.
- In terms of proximity of the opportunities, some of the low-hanging fruit can be done quickly. There are projects within the National Digital Twin Programme that are due to deliver something tangible this year.
- Traditional transport models, and the skills and capabilities around them, can be a natural foundation for developing digital twins.

6.9 The following points were raised addressing the second and third questions listed until 6.7, concerning what can be done to realise these opportunities:

- Maintaining the data for digital twins is difficult and costly, and someone will need to pay for it. Currently, many organisations are not good at looking after digital assets (e.g. data, code and algorithms) in the way that they look after physical assets, because they do not value them appropriately. A clear ‘value proposition’ needs to exist to justify the expense of operating a digital twin, and assessing this can be challenging. Current accounting approaches are often not adequate for assessing investments in data use and modern technology, such as digital twins.
- Ownership of connected digital twins, and their aggregated data and insights, will be a complex issue. Private companies will want to protect the commercial value that justified their substantial investment in developing and maintaining digital twins. Connected third-party digital twins could imply external interventions that will change something that a private company owns or derives value from, presenting risk. Experience shows us that, even when identified, it is difficult to implement interventions on complex, high-value systems affecting multiple organisations.
- Rather than presuming that we need digital twins, there ought to be a rigorous cost-benefit analysis of use cases, and DfT could identify where within transport they are really worth the cost. In many cases a simpler surrogate model may be a better alternative to a digital twin, giving a lot of the same benefits with fewer barriers and greater flexibility.

- DfT could provide leadership in developing a roadmap to unlock the opportunities of digital twins, with a clear vision of what this is worth to the UK, outcomes and timescales.
- With transport as a potential key user of digital twins, DfT could provide support to the proposal for the future National Digital Twin Programme, to secure funding and promote its approach of an Information Management Framework.
- Linking up with the National Digital Twin Programme, DfT could provide a foundational model for use of digital twins in transport, which the different transport modes could coalesce around. Common data standards and other enablers could then be developed to link individual projects to the vision, increasing their value.
- Rather than multiple small projects that add little value, there would be benefit from clear leadership for coordinated action on digital twins within major transport organisations, and to provide the linkages between them. DfT could play a role in facilitating this coordination across the sector, especially through its arm's length bodies.
- DfT could take the lead in addressing the key underlying requirements of enabling and motivating data sharing and improving data quality in transport. The availability of data ought to be based on the intelligence required, rather than the intelligence being based only on the data available - as is too often the case currently.
- One argument for digital twins is that they are cheaper than physical experimentation, but they depend on sensors and sensors can be expensive. If and where they are deemed to represent value for money, then DfT could take the lead in requiring sensors to be installed in new projects and infrastructure.
- A cross-transport sector network of expertise in this area would be valuable, and DfT could convene this.
- It would be valuable for government to assess whether our universities are providing the skills needed for wide scale implementation of digital twins, and, if not, what should be done to address this.
- DfT could benefit from learning from international activity where possible. Boston and Singapore are among the places taking a city-wide approach to digital twins.

6.10 After the departure of additional attendees, SAC members discussed their conclusions from the discussion:

- Digital twins are not a panacea, and it is important to be clear where they will offer real value and to who. Digital twins should be driven by purpose and do not need to capture and analyse every element of the system.
- It has always been a challenge to move towards a more integrated transport system. Connected digital twins could represent an integrated digital transport system. Is this any easier to achieve, and the route to better integration of the physical system, or not?
- Quality and trust in data is essential. Although it was downplayed in the discussion, it still seems important that other components of the digital twins also be certified so that they can be used and connected to other digital twins with confidence.
- Promoting data sharing is a major issue, and there is a question about whether DfT takes an approach of mandating this or seeking to demonstrate its value to those owning the data. The SAC has discussed this in the past and demonstrating the business models for commercial organisations to readily share data remains a key challenge for researchers and government. Experience shows that at a practical level it is really challenging to share data effectively, even when parties are willing.

- DfT and others will need to think about requirements on data use and storage for regulatory and auditing purposes.
- One of the issues identified in the discussion was that sharing data and digital twins creates ownership issues. With this comes major issues around the liability for decisions based on data from various sources. DfT may need to understand and address these liability issues.
- Embedding the skills needed for digital twins and similar technology within the transport sector will be a challenge, and will not just happen. There would be value in an assessment of whether current university engineering courses address the need for data-centric engineering. There will also be a need to upskill those already in the workforce, and (as has been suggested before) a national transport data centre could be established to work with DfT and transport organisations to bring skills into the sector.
- It will be valuable for DfT to develop a clear understanding of the ecosystem around digital twins, and the (potential) role of organisations such as the Connected Places Catapult, Turing Institute, and the new Advanced Research and Invention Agency.
- DfT could provide valuable guidance to the sector, and particularly its arm's length bodies, on the approach to this technology.
- It would be very beneficial for DfT to engage with the proposed future development of the National Digital Twin Programme, and help shape it from a transport perspective.

Annex C: 28 September meeting minutes – Science for a resilient transport system

These minutes summarise the range of independent views and opinions expressed during the meeting, without generally attributing these to individual attendees. Individual opinions may not be the view of the SAC or group of attendees as a whole. Neither individual views nor SAC advice should be taken as representing the positions of DfT and DfT ministers.

DfT Science Advisory Council

11:00–14:00 Tuesday 28 September 2021

via videoconference

SAC members attending

- Professor Lord Robert Mair, Chair
- Professor Ally Lewis, Chair-elect
- Anna-Marie Greenaway
- Professor Barry Clarke (item 6 only)
- Dr Dave Smith
- Professor Nick Pidgeon
- Professor Peter Jones
- Professor Ricardo Martinez-Botas
- Professor Rob Miller

DfT attendees

- Professor Sarah Sharples, Chief Scientific Adviser
- Dr Siobhan Campbell, Head of Central Research Team
- Head of Science Strategy – Office for Science
- SAC Secretariat

Additional attendees for item 4 only

- Bernadette Kelly, DfT Permanent Secretary
- Professor Phil Blythe, previous DfT Chief Scientific Adviser

Additional participants for item 6 only

- Dr Alexandra Smyth, Senior Policy Adviser, Royal Academy of Engineering
- Professor Cath Noakes, Professor of Environmental Engineering for Buildings, University of Leeds
- Professor Liz Varga, Professor of Complex Systems, University College London
- Dr Mark Harrison, Strategic Head, UK Applied Science, Met Office
- Professor Stephen Belcher, Chief Scientific Adviser, Met Office
- Head of Strategy and Science Cell, Domestic COVID-19 Directorate, DfT
- Head of COVID-19 Science Cell, DfT

Apologies

None

1. Review of May meeting minutes

1.1 The minutes of the May meeting were agreed without amendments.

2. Appointment of new SAC Chair and members

2.1 The Chair and Sarah Sharples congratulated Ally Lewis on his appointment as incoming SAC Chair. Sarah updated the SAC on the recruitment of new members, which would be complete ahead of the next meeting in December.

2.2 Professor Lewis gave an overview of his research interests in atmospheric chemistry and air quality, and experience providing advice to policy-makers, including as current Chair of Defra's Air Quality Expert Group. He highlighted his desire to see UK research strengths be further translated into a competitive advantage for the UK.

3. Chief Scientific Adviser's update

3.1 Sarah Sharples gave reflections on the use of science within DfT, from her first two months as Chief Scientific Adviser.

3.2 The SAC welcomed the overview, and particularly the highlighted opportunity for the SAC to support advocacy of science within DfT, including integration of deep science evidence and expertise with policy, and supporting horizon scanning and foresight. SAC members stated their willingness to engage more as individuals and/or small groups with colleagues across DfT on specific topics in line with their interests and expertise.

4. Farewell to Robert Mair as outgoing SAC Chair

4.1 This was Robert Mair's last meeting as SAC Chair. Sarah Sharples, Phil Blythe, the previous Chief Scientific Adviser, and Bernadette Kelly, DfT Permanent Secretary, led the thanks to Robert for his outstanding contribution in the role since 2014.

4.2 Professor Lord Mair reflected on his time as Chair and the achievements of the SAC. Looking forward, he noted the importance of SAC work being led by policy needs and of reenergising the engagement between SAC and DfT's senior leadership. He thanked SAC members, Phil Blythe, Siobhan Campbell and the SAC Secretariat for their support, and wished Ally Lewis well as his successor.

5. DfT Science Plan

5.1 An introduction was given to the three pillars of the DfT Science Plan − People, Purpose and Partnerships − and the SAC was invited to consider:

- Which of the identified actions should be prioritised by DfT when implementing the Science Plan?
- Which actions are SAC members particularly interested in, and where might SAC members be able to provide assistance or guidance to DfT in the implementation of the Science Plan?

5.2 SAC members stressed the importance of clearly describing and maintaining focus on priority outcomes to constantly inform prioritisation of actions. The SAC recognised the People pillar of the Science Plan as the long-term key to achieving its aims, but noted that skills development takes time and consistent focus. Members felt the SAC should continue and strengthen its role supporting foresight activities and roadmapping of pathways towards identified outcomes. It was noted how COVID has demonstrated the importance of agile, iterative working between government and those doing deep systems thinking on complex issues, and that DfT needs to interact effectively across government and the research ecosystem. Members were particularly keen that the SAC actively support the following actions:

- Develop deep skills in some DfT science experts in identified priority areas (for example data science, systems engineering, behavioural science) (Action 3)
- Develop a mechanism to enable DfT to have rapid access to deep skills across the external R&D sector (Action 4)
- Develop DfT's ability to understand and manage the opportunities and risks around emerging technologies (Action 29)
- Pilot a new internal Futures and Uncertainties Portal to provide guidance on the application of tools and methodologies, and latest information on key uncertainties and trends (Action 30)

6. Science for a resilient transport system

6.1 The Chair welcomed attendees for this item and noted the background paper provided in advance to frame the discussion.

6.2 An introduction was given to DfT's current approach to science for resilience, including the following points:

- DfT's Transport Security Resilience and Response directorate lead this area, with the National Security Science and Research (NSSR) division within it delivering advice, evidence, standards and new capabilities.
- DfT maintains a consolidated risk audit matrix based on reasonable worst-case scenarios, likelihood, impacts and mitigations. Science provides vital evidence to these assessments.
- HM Government's Integrated Review of Security, Defence, Development and Foreign Policy and developing National Resilience Strategy provide the high-level drivers for this work.
- To complement existing work, NSSR has a dedicated (non-security/cyber) Science for Resilience Programme in development, structured around existing and future risks. DfT's COVID-19 directorate are also developing specific work on infection resilience.
- It would be valuable to increase understanding of some of the specific impacts of risks on transport and, from this, how science and technology can best be used to address the risk. DfT recognise the importance of interdependencies of risks.
- NSSR are keen to continue this conversation and further broaden their network of external contacts and sources of advice. DfT's published Areas of Research Interests is a useful reference containing some of DfT's priorities for resilience science.

6.3 A presentation was given on the Met Office's work on science for climate resilience, including projects for the DfT, which included the following points:

- It is beneficial for risk to be understood and communicated as three components – exposure and vulnerability as well as hazard.
- The Met Office is keen to better understand how its science is and can be used within DfT and more widely. There would be benefits to developing a closer, less transactional relationship.
- The Met Office are doing a substantial amount of work related to autonomous vehicles, where humans are removed from the decision-making process. Uncertainty is unavoidable in describing weather, and this is a good example of the need for automated systems to be able to explicitly handle uncertainty.
- Understanding risk and building resilience is a shared endeavour, and the key is how we create the right frameworks and relationships to support this. Approaches such as hackathons, user groups, researchers being embedded in other policy/delivery organisations, and learning labs can help.

6.4 A presentation was given on the recent Royal Academy of Engineering (RAEng) report on infection resilient environments, and lessons from COVID-19 for an infection-resilient transport system:

- The Government Chief Scientific Adviser, Sir Patrick Vallance, commissioned the Royal Academy of Engineering to explore how buildings and transport can be redesigned and managed to make them more resilient to infection, and steps that should be taken ahead of winter 2021/22 to operate them in a way that reduces the risk of COVID-19 transmission.
- The work included evidential hearings with owners and operators across a range of environments, which revealed differences between stakeholder understanding and considerations and the 'bare' science. It is important to understand and resolve such misalignments.

- The report recommends that clear communications should be accompanied by accessible and trusted guidance, and that this general guidance should be underpinned by rapid and specific technical guidance, to use science evidence effectively.
- Other recommendations focussed on the importance of the government's role in understanding and supporting the knowledge and skills requirements across relevant industries and regulators to deliver infection resilience environments, covering education right through from school to continuous professional development. Gaps can exist between regulations and what there is the capabilities to deliver and enforce.
- The report recommends that government policy on net zero should be developed in a way that is consistent with priorities around indoor air quality and making buildings resilient to infection.
- Key lessons from the science response to COVID-19 include the absolute importance of collaboration between all stakeholders to challenge assumptions and give a breadth of perspectives, and the importance of social and behavioural science to understand the human perspective. The TRACK (Transport Risk Assessment for COVID Knowledge) project (which Professor Noakes leads and DfT have supported) was cited as an example of close collaboration between scientists, policy makers and transport operators.

6.5 Attendees were asked to consider how science can be used most effectively by DfT and others to support delivery of a resilient transport can system:

- What does a more resilient transport system look like and how does science and technology enable it?
- What can we learn about science for resilience from the experiences of COVID?
- What cross-cutting themes and approaches can apply to the use of science for resilience across different risks, and where might there be a need specific approaches to particular risks?
- How can DfT best prioritise actions to use i) existing science knowledge and ii) new research to understand, prevent and mitigate the range of risks and hazards?

6.6 In discussion, attendees identified the following key points:

- Modern transport systems are inherently less resilient in some ways. Increased efficiency in system design and operation can result in less resilience to risks and extreme events, and failures of digital systems have potential to cause disruption that is more widespread than would result from physical system failures alone.
- Give the cost of building-in resilience, it is important to have a clear understanding of what an acceptable level of resilience looks like – e.g. maintaining X% network capacity under a certain scenario.
- Effective partnership working across disciplines and perspectives, including scientists, operators and users, is crucial to really understanding complex risks and possible unintended consequences, and these relationships benefit from being established in ‘peace time’ rather than during a crisis.
- Linked to this, it is important to share a common language around risk and resilience, including understanding the breakdown of risk into “hazard, vulnerability and exposure.” There is academic literature on the concept of “resilience literacy” and the

importance of adopting language that people can engage with to support social preparedness.

- It is important to take a systems approach to identify interdependencies between multiple risks and with other policy priorities such as net zero. This is highlighted in current work by the Royal Academy of Engineering to review HM Government's National Security Risk Assessment methodology and to consider critical capabilities, interdependences of risk and compound events. It is important to try and design-in resilience but have the ability to adapt.
- Our ability to adapt and respond can be increased by continuously learning about complex systems using smart-sensing monitoring and data science. Again, the necessary data flows and systems should be established in 'peace time.' Digital twins could help explore resilience scenarios, though the benefit of simpler models was also supported.
- Transport is a complex socio-technological system, and social and behavioural aspects of resilience are crucial, including understanding behaviours and social/public preparedness. The National Preparedness Commission are doing important work in this area.
- Network Rail has recently published two independent reports, led by Robert Mair and Dame Julia Slingo, assessing the national rail network's ability to withstand extreme weather. These were commissioned following the fatal derailment in Stonehaven, Aberdeenshire, in August 2020 caused by a landslip after intense rainfall. The reports cover a lot of important considerations relevant to transport resilience more broadly and are important references.
- It is important to take lessons from COVID-19 but think about possible future challenges and risks, rather than preparing for past events.

Annex D: 15 December 2021 meeting minutes − New members and forward planning

These minutes summarise the range of independent views and opinions expressed during the meeting, without generally attributing these to individual attendees. Individual opinions may not be the view of the SAC or group of attendees as a whole. Neither individual views nor SAC advice should be taken as representing the positions of DfT and DfT ministers.

DfT Science Advisory Council

10:30–14:00 Wednesday 15 December 2021

Via videoconference

Council members attending

- Professor Ally Lewis, Chair
- Anna-Marie Greenaway
- Dr Dave Smith
- Dr Emma Taylor
- James Gaade
- Professor Nick Pidgeon
- Professor Patricia Thornley
- Professor Peter Jones
- Professor Ricardo Martinez-Botas
- Professor Rob Miller
- Dr Siddartha Khastgir
- Professor William Powrie

DfT attendees

- David Coles, Chief Engineer

- Professor Sarah Sharples, Chief Scientific Adviser
- Dr Siobhan Campbell, Head of Central Research Team
- Head of Science Strategy – Office for Science
- SAC Secretariat

Apologies

- Professor Barry Clarke

1. Welcome and review of September meeting minutes

1.1 The Chair welcomed attendees, including the five newly appointed members.

1.2 Barry Clarke sent his apologies for this meeting and conveyed that he felt that this was the right time for him to step down from the SAC, following the appointment of new members and given his upcoming retirement in March. Barry has been a member of the SAC since its formation in 2014 and the Chair thanked him for the huge contribution he has made and passed on a further message of thanks from the previous SAC Chair, Professor Lord Mair.

1.3 The Chair reminded members of the expectations on them to act impartially and in keeping with the Seven (Nolan) Principles of Public Life, and to exercise discretion in relation to SAC and DfT business and maintain confidences where agreed.

1.4 The minutes of the September meeting were agreed without amendments.

2. Chief Scientific Adviser's introduction to DfT

2.1 The CSA gave an introduction to DfT's use of science and engineering, including:

- the structure of science and engineering within DfT
- key external interactions across government and with arm's length bodies, UK Research and Innovation, and academic groups
- her CSA's mission to further embed research, development and demonstration (RD&D) thinking within DfT via providing advocacy, assurance, support and influence
- DfT's developing RD&D priorities in support of its strategic priorities
- the role of the Transport Research and Innovation Board in providing coordination of activity and investment across the UK transport research and innovation community to make activities strategic, impactful and world-leading.

2.2 The SAC can support her ambitions for delivery of the DfT Science Plan, by supporting:

- the development and networks of scientists and engineers within DfT
- DfT's collaboration with UKRI and academia, and being representatives of DfT activity in their own professional settings

- the provision of science to improve policy and delivery, including specifically to deliver cost savings, improve transport for the user, and reduce environmental impacts.

3. Introductions from members

3.1 All members presented a slide introducing themselves and their areas of expertise to give a clear understanding of the expanded breadth of knowledge and skills now offered by the SAC.

4. Role and operation of the SAC

4.1 Continuing SAC members led an item on what is working well in the SAC, what the challenges are, and what could be changed or improved. The following points were identified:

- There should be a clear mechanism and rolling cycle for reviewing the impact of SAC discussions and outputs, to provide understanding and help maximise their value – and that of the SAC – to DfT.
- The SAC was keen to continue and enhance its functions of horizon scanning, testing the underlying science and technology assumptions informing DfT's work, and supporting specific requests for evidence.
- The format of 'deep-dive' discussions, addressing specific "questions to the SAC" with input from additional subject matter experts, was felt to be effective. SAC members could be involved more in planning to ensure the questions are the right ones.
- Focusing ongoing SAC work around a few priority areas may help maximise the SAC's impact and achieve a valuable legacy in those areas.
- Generally, the SAC can be most useful by providing early input aligned with DfT activity, rather than reviewing later-stage outputs of detailed DfT work. As well as 'deep-dives' leading to more formal advice, the SAC could also be asked and should be able to provide informal input on DfT ideas and work at very early stages of development. DfT's Joint Analysis Development Panel does this well.
- There could be more flexible and regular engagement of individual SAC members and subject-specific sub-groups with teams across DfT, with SAC members accessible to officials for ad hoc advice outside formal meetings. It would be beneficial for SAC members to have a relationship with the lead DfT official relevant to their specialist area.
- The SAC, and individual members, should act as an access route to an even broader list of external experts. Linked to this, the CSA and her team are looking into developing a wider 'DfT College of (external) Experts.'
- Members were keen to re-energise dialogue with Ministers and DfT's senior leaders, including repeating the type of event previously held with DfT senior officials in May 2018.
- SAC members expressed enthusiasm for a mutual mentoring programme with more junior colleagues in DfT. The Secretariat took an action to investigate with colleagues how to take this forward (**Action 21/12-1**).

5. Strategic priorities from members

5.1 All SAC members and senior DfT attendees presented on an emerging strategic science and technology topic of interest to them. The following topics were raised:

- Systems thinking and cross-sector analysis and cooperation, including in relation to decarbonisation, urban planning, transport and sectors generating transport demand, cross-sector demand for resources
- Opportunities to fundamentally re-imagine our towns and cities
- Local impacts on communities from changes to our energy systems
- Routes to achieving net-zero (it was recommended DfT consider the report on the role of energy demand reduction from the Centre for Research into Energy Demand Solutions (CREDS))
- Understanding how much combustion will be retained in future transport systems, and environment and health impacts of this
- Sustainable fuels covering biofuels and electrofuels, and including: appropriately evaluating the carbon intensity, overall resource efficiency, and other impacts of low carbon fuels; enabling future fuels which alleviate pressure on electrification and support the transition to vehicles that are affordable, desirable, sustainable and efficient; and sustainable aviation (the work of the Jet Zero Council Sustainable Aviation Fuels Group was noted)
- Systems challenges and opportunities in cybersecurity
- Using science and technology advice to deliver systems that are 'secure by design,' rather than security being added on at increased cost and inconvenience
- Mechanisms for responding effectively to emerging technologies
- Delivering infrastructure efficiency in terms of cost and carbon (an Institution of Civil Engineers review into taking a systems approach to infrastructure delivery was noted)

6. SAC topics for 2022

6.1 Attendees discussed potential priority SAC work areas for 2022, informed by item 5 and two meeting papers on past SAC work and existing SAC topic suggestions. The following high-level priority themes were agreed:

- Future fuels
- ‘Secure by design’ transport
- Systems approach to decarbonisation
- Re-imagining travel and communities; to include urban and rural, all transport modes and elements of improving transport for the user, including cost

6.2 A lead SAC sponsor and DfT sponsor will be sought for each theme. Initial offers to sponsor themes came from Emma Taylor for Secure by design, and William Powrie for Re-imagining travel and communities.

6.3 The SAC should also support and feed into work on air quality issues. Two members are already involved in current work on this led by the Chief Medical Officer, and the SAC might further support this.

6.4 It was agreed that the SAC should also have some opportunities to look further ahead to more distant or seemingly outlandish technologies and developments, and to consider their potential longer-term impacts.

6.5 The Chair, CSA and Secretariat will develop these thoughts into an outline proposal for SAC's 2022 work plans, in consultation with DfT policy and delivery teams to ensure maximum impact of SAC activity (**Action 21/12-2**). SAC members will be involved in development of plans and of SAC sub-groups.

Actions

Action	Description	Target date	Owner
21/12-1	Investigate mutual mentoring programme between SAC members and DfT colleagues	Ahead of next meeting, March 2022	SAC Secretariat
21/12-2	Develop outline proposal of SAC 2022 work plans to share with members	Mid-February 2022	SAC Secretariat