Innovation for Sustainable Airports

A Science and Innovation Audit Report sponsored by the Department for Business, Energy & Industrial Strategy

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Sustainable Airports

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Brunel University London

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The Consortium would like to thank the local and national businesses and academics whom provided their views and insight to this Science and Innovation Audit.

Consortium Partners

Foreword

Science and Innovation Audits, introduced in 2015, have helped provide evidence of the different science, innovation and industrial environments of places across the UK, and how they might best contribute to improving the UK's productivity and to growing exports. In late 2017 the UK government published a white paper, *Industrial Strategy: building a Britain fit for the future.* As well as detailing a range of plans and proposals for strategic government intervention in the development of the UK economy and industry, it reaffirmed the government's view of the importance of Place, describing it as one of the 'five foundations of productivity.'

This SIA differs from others completed in waves 1 & 2, in that it takes a whole ecosystem approach around a specific business, London Heathrow Airport. In doing so, we view Heathrow as both an 'Anchor Business' for the 400 businesses that come together to operate Heathrow and their supply chains, and as a 'Connectivity Institution', enabling people and products from across the UK to connect with the emerging economies within Asia and South America.

Maintaining Heathrow's position as a world leader in the efficient use of airport capacity, and continuing to operate an expanding airport within a fixed or shrinking environmental footprint, will require continual technological innovation. In the audit, we show how innovative companies in the area to the west of London, supported by the science and innovation strengths of the region, can deliver the future technologies for sustainable airports. We also illustrate how Heathrow can act as an asset for growth, pulling technologies out of the lab into operation, and as a demonstrator and a show-case for these innovative technologies.

With 42,000 airports in the world, and world air passenger numbers set to double over the next two decades, there are substantial opportunities for the innovative businesses in the Heathrow supply chain to expand their exports, increasing the productivity of their region. This report identifies a number of technology areas where this will be possible, and evidences where this is already happening. The SIA also details a range of measures designed to support and accelerate this change, ensuring that the airports sector drives the economic growth and creates the highly productive jobs to deliver a Britain fit for the future.

Professor Geoff Rodgers

Deputy Vice-Chancellor, Brunel University London

Executive Summary

This SIA is unique in focussing on the geography surrounding Heathrow Airport and the strength in delivering the innovation needed to support sustainable airports. The report presents our findings and includes analysis of the study area's capabilities and the challenges and substantial opportunities for future economic growth.

Focussing on key themes such as Sustainable Construction; Big Data and Cyber Security; Operational Excellence and Intelligent Mobility, the report shows how as an anchor business Heathrow can drive and showcase innovation. The report defines the barriers to exploiting such innovation and recommends that the research excellence in the region is harnessed to ensure innovative technologies for future airports are developed and translated into increased exports, increased productivity and economic growth.

INNOVATION FOR SUSTAINABLE AIRPORTS
SCIENCE AND INNOVATION AUDIT

OUR STUDY AREA

Heathrow is the largest hub airport in Europe, with 476,000 aircraft movements annually, an exemplar in the 'industry' as the world's most efficient 2-runway airport, because of the systems, processes and culture that support Heathrow's daily operation. Our study area of West London and the Thames Valley, includes 5 LEPS which are, Buckinghamshire Thames Valley, Enterprise M3, Hertfordshire, London and Thames Valley Berkshire.

HEATHROW

Heathrow is the UK's most important port, with a total trade value of £121bn in 2017, 30% of the UK total

TOTAL BUSINESSES	AVERAGE EARNINGS
145,000	2.6% Higher than the national average

8.99% Percentage of the total workforce employed in science, research, engineering & technology professions

Compared to the national average of 5.6%, which contributes to the higher productivity of the study area.

52% Proportion of the population employed in science, engineering and technology

In comparison to 43% nationally, based on Nomis official labour market statistics

MARKET OPPORTUNITY

The global aviation industry is growing significantly with the International Air Transport Association predicting a near doubling of air passengers from 3.8 billion in 2016 to 7.2 billion passengers in 2035.

There are 42,000 airports across the world and currently over 400 major construction projects going on, with between 20 and 30 new airports under construction. It is estimated that £1trillion in airport infrastructure projects are planned or under way.

£24.6 billion
Global airport spend on cyber security and cloud services in 2017

£52bn
Added to the UK's GDP by aviation, supporting substantial inward investment and almost one million jobs

96% of airports
Planning major programs of Cyber Security investment and Cloud Services over the next 3 years

RESEARCH AND INNOVATION STRENGTHS

Heathrow acts as an Anchor Business for more than four hundred businesses that operate the airport (employing 76,500 people), and hundreds more across the UK in their supply chains. As the only UK hub airport, Heathrow connects UK businesses to global economies and opportunities.

- Four medium-sized research intensive universities are clustered around Heathrow, with a powerful combined research power:

- Brunel University London
- Royal Holloway University of London
- University of Reading
- University of Surrey

Brunel's Engineering and Design capabilities are ranked amongst London's biggest and best.

- These universities are involved in a range of international research partnerships, including 175 Horizon 2020 research projects worth £156M, and with over 40% of their EU funding (by value) in ICT and transport.
- 230 research organisations in the study area

BRE
A world leading multi-disciplinary building science centre with a mission to improve the built environment through research and knowledge generation. Their Innovation Park - features over 300 construction innovations and emerging technologies being evaluated and attracts thousands of visitors from around the world every year.

DIGITAL TECH CLUSTER
The Thames Valley digital technology cluster comprises 7,800 digital technology companies, the highest concentration in the UK, employing 56,300 digital technology specialists and generating 600 new start-ups per annum.

RECOMMENDATIONS INCLUDE

- Innovation/Research Centre for sustainable airports
- An Airport Habitat Lab
- A West London Connected Autonomous Vehicle Cluster
- Export Strategy for sustainable airport technologies
- Research Cluster on Sustainable Construction
- Smart, sustainable, scalable supply chains
- Develop activities to meet innovation skills gaps
- The use of Heathrow as a demonstrator for multi-modal mobility as a service

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Appendix 2: Innovation for Sustainable Airports: Data Report

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1 Introduction

In Autumn 2015, the UK Government announced Science and Innovation Audits (SIAs) to catalyse a new approach to regional economic development. SIAs enable local consortia to focus on analysing place based strengths and identify mechanisms to realise their potential. In the Thames Valley and West London, a consortium was formed in 2017 to focus on our strength in Sustainable Airports. This report presents the results which includes broad-ranging analysis of **West London and the Thames Valley's** capabilities, the challenges and the substantial opportunities for future economic growth.

Our consortium, led by Brunel University London, includes partners representing the LEPs, SMEs, universities, research organisations, business & trade organisations, industry, and local and national government. Heathrow Airport Ltd is in our consortium and has been hugely supportive of this SIA.

The hypothesis that this Audit will explore is that:

> ***Science and innovation excellence supporting 'Sustainable Airports' within our study area can be boosted to drive further innovation in the UK, and to enable global exploitation.***

1.1 Context

Two important factors provide a context for this audit; the impending decision on the development of London Heathrow Airport, and the strong economic performance of this region in comparison with the rest of the UK.

Heathrow is currently the most efficient two-runway airport in the world, operating at 98% of capacity. The Davies[1] review recommended a third runway at Heathrow with a package of measures to address environmental and community issues. By 2030 it is predicted that Heathrow will carry 104M passengers per annum and that by 2040, expansion will add 76,700 new jobs and raise UK Gross Value Added (GVA) by £3bn.

The airport is embedded in an SIA study area[2] (the 'study area') that has enjoyed 27% increase in GVA since 2010, in comparison with a 23% increase nationally. The study area has high productivity with a GVA per person of £36,500 compared with the UK average of £25,000.

This SIA takes a whole ecosystem approach around Heathrow, considering it both as an 'Anchor Business' and a 'Connectivity Institution' providing a focus for businesses and growth. These are assets encouraged in the Industrial Strategy.

Heathrow acts as an Anchor Business for more than four hundred businesses that operate the airport (employing 76,500 people), and hundreds more across the UK in their supply chains.[1] This includes businesses across a breadth of digital creative, technology and infrastructure areas that present huge opportunities for growth and technology exploitation.

As the only UK hub airport, Heathrow is the UK's most important Connectivity Institution, ensuring that UK businesses can compete in the race to connect with the emerging economies within Asia and South America. This benefits businesses across the UK, not just within our study area.

Heathrow is also the UK's most important port, with a total trade value of £121bn in 2017, 30% of the UK total.[3] By value the most important sectors are mechanical appliances (including energy production apparatus), precious stones, metal and pearls, pharmaceutical products and electrical equipment. These are all areas where increasing exports will drive improvements in productivity and create both jobs and economic growth. 95% of these exports were transported in the hold of passenger planes, by combining business need for exports to a destination with the pooled passenger demand of a hub, the UK gains greater access to emerging economies and more frequent flights to destinations.

Furthermore, airports can act as an asset for innovation led growth, pulling new technologies and processes out of the lab and into use, and demonstrating these ideas to a large number of people. For instance, the pioneering work of Heathrow on the electric autonomous pod vehicles, Gatwick's process for re-developing the North Terminal and Manchester Airport Group's MAG-O initiative to improve the passenger experience all demonstrate the 'living lab' contributions of airports to the innovation landscape.

The consortium partners chose four themes for the SIA to focus on; Sustainable Construction, Big Data and Cyber Security, Operational Excellence and Intelligent Mobility.

These themes were chosen as a way of classifying the future technology needs of sustainable airports, and the regional research and innovation excellence that will help develop these technologies.

1.2 The Geography for the SIA – Our Study Area

The study area of the Innovation for Sustainable Airports SIA is illustrated in Figure 1 and comprises the boroughs surrounding the airport and the districts along the Thames Valley to the west of the airport. The study area spans districts within 3 regions: London, the East and the South East. It spreads across 6 counties, 19 districts or local authorities and 5 LEPs. The five LEPs are Buckinghamshire Thames Valley, Enterprise M3, Hertfordshire, London and Thames Valley Berkshire.

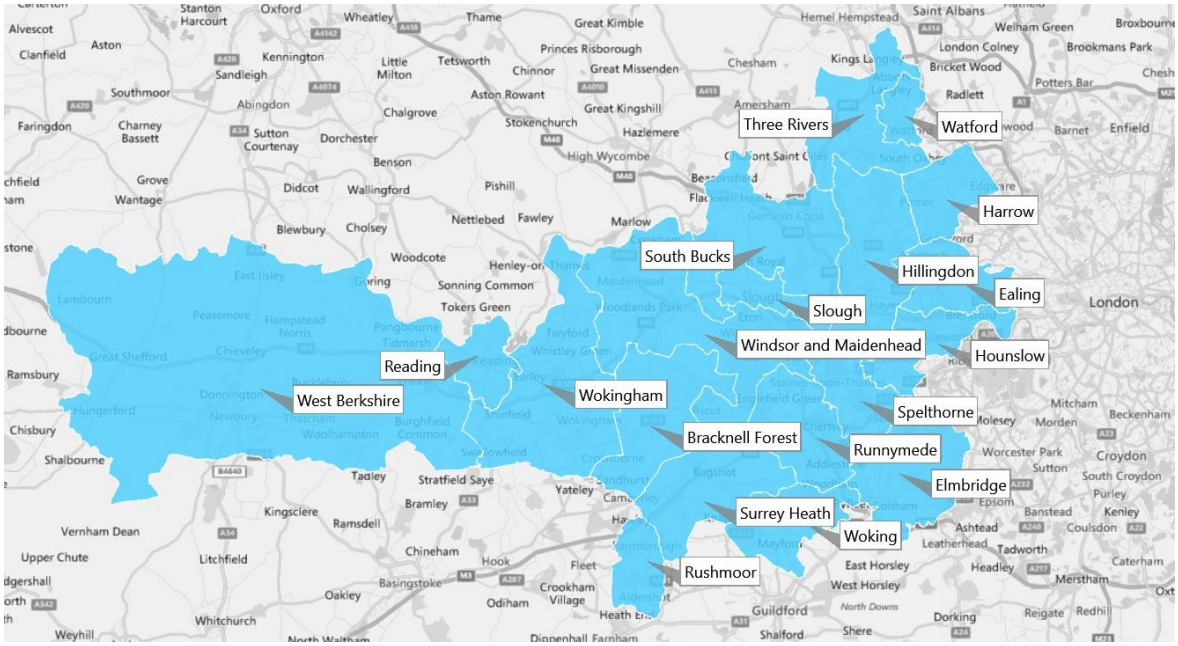


Figure 1: The Sustainable Airports SIA Study Area

Within the study area there is a population of 3 million people, of whom 1.9 million are of working age.[4] There are 145,000 businesses, or nearly 50 per 1000 capita.[5] Average earnings are 2.6% higher than the national average and grew by 4%[6] between 2015 and 2016 in comparison with a 2.2% growth nationally.[6]

Employment is high, with a job density, the ratio of jobs to population of 0.92[7]. Within the study area, the proportion of the population employed in science, engineering and technology is 52% in comparison to 43% nationally.[8]

The Gross Value Added in the study area grew to over £100bn[6] in 2015. The largest broad industrial group is 'distribution; transport; accommodation and food' accounting for over 23% of the GVA, followed by 'information and communication' (15% GVA), 'business service activities' (14% GVA) and 'real estate activities' (13% GVA). In total these four broad groups account for over 65% of the total GVA.[6]

The study area benefits from a high number of business start-ups, and most of our five LEPs outperform the UK average for the growth of start-ups and medium sized enterprises.[9] Industrial land values are high in the study area,[10] and Heathrow expansion could see a 10Msqft increase in the requirement for industrial space in the study area.

The location of the Heathrow Airport employment site at the intersection of four LEPs (Figure 2) creates a range of challenges for place based planning and place based industrial strategy considerations. This SIA will be a key enabler and tool in this process and the consortium has strong links with the Heathrow Strategic Planning Group[11] to connect with the range of authorities represented in the study area. Both groups have highlighted that the 'Heathrow economic area' would benefit from having its own identity and therefore focus.

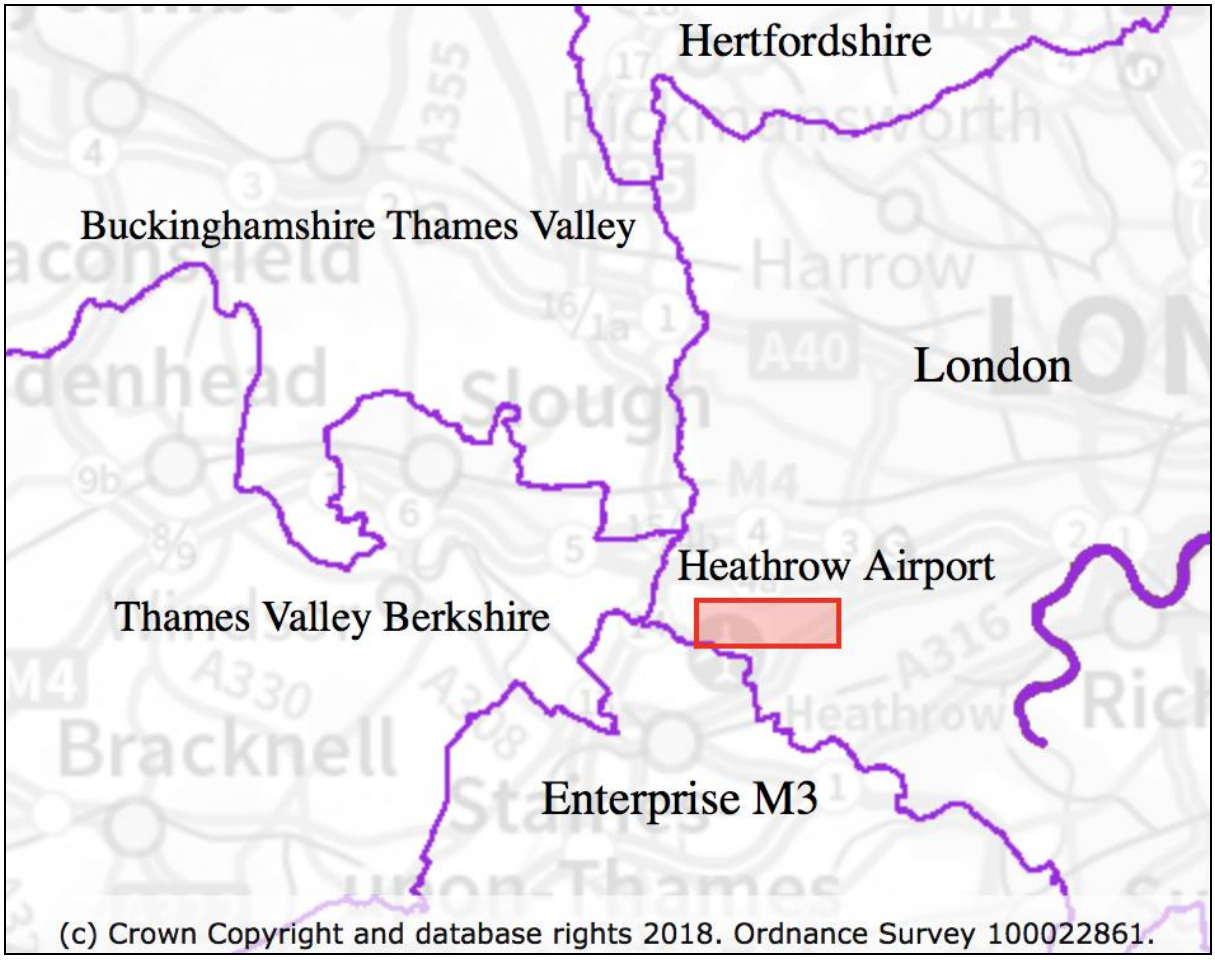


Figure 2: The Five LEPs covered by this SIA and Heathrow Airport at the intersection of four of them.

Within the study area Heathrow Airport is the largest employment site and generates 1.5% of UK GDP.[12] It is recognised for excellence in customer experience and operational efficiency. It is also an internationally recognised leader in environmental sustainability.[13] To maintain its position as the most efficient 2-runway airport in the world, with aviation growing globally, research, innovation and business collaboration will be critical for this growth to be sustainable.

Within the study area the six broad industrial sectors with a concentration greater than the national average are:[14]

Information & Communication	Professional, scientific & technical	Transport & Storage
Wholesale	Business administration	Property

The single standard industrial classification of economic activities which is greater than the national average is air transport. This is evidence of the agglomeration effect driven by the airport.

As Britain's international Gateway Heathrow Airport plays a vital role in supporting the UK's economy, its importance in linking British innovation to the rest of the world cannot be

underestimated. Nowhere is this more critical than across the Cambridge, Milton Keynes, Oxford Growth Corridor (CaMKOx) which adjoins this study area in Buckinghamshire and has been highlighted as a region which could provide Britain's equivalent to Silicon Valley. The four LEPs in the corridor area are currently working on the delivery of one of three trailblazer Industrial Strategies which is focussing on the international growth and productivity potential of the region and the development of the economic ecosystem.

The National Infrastructure Commission's 2017 Partnering for Prosperity[15] report into the potential of this corridor set a target of 1 million new homes and 1.1 million jobs for 2050, this scale of growth combined with the pressures already identified in the draft London Plan mean that protected high quality employment and research space will increasingly be at an even greater premium in the study area.

The area around Heathrow airport is currently characterised by 3 complementary but distinct highly productive economies. The Thames Valley and Berkshire has a strong base of corporate headquarters and technical and scientific research specialisms, Buckinghamshire and Hertfordshire's economies are driven by entrepreneurial SME and Micro business capabilities and the West London area is more typical of a capital city with a younger demographic, a more cosmopolitan and international workforce and established sector specialisms in industrial logistics.

2 Strengths in Science and Innovation

2.1 Excellence in Science and Research

There are 230[16] research organisations in the study area, and four medium-sized research-intensive universities are clustered around Heathrow to the west of London: Brunel University London, Royal Holloway University of London, University of Reading, and University of Surrey.

These institutions have numerous connections with the airport, and many excellent examples of how their world leading research has improved the productivity and sustainability of airport operations. Between them these institutions submitted 2,136 academic staff to the Research Excellence Framework (REF) 2014, and all four were in the top 40 UK institutions for research power.[17] If combined, their REF submissions would have been ranked as the 3rd university in the UK for research power, with the 4th largest volume of world leading and internationally excellent (4* and 3*) activity.[17] According to the RCUK Gateway to Research, these universities have 839 active research projects supported by £480M of funding[18] and have substantial overseas research partnerships, having participated in 175 Horizon 2020 research projects worth £156M.[19] Together, these institutions employ 11,593 people[20] and produce 21,096 graduates[21] per year.

More broadly, there are 41 universities in the enlarged area[22], if one extends the study area by 10 miles in all directions, offering a range of complementary expertise and attributes. Each plays an important role in the study area's innovation ecosystem in terms of the provision of higher-level skills and expertise and the provision of research, innovation, enterprise, consultancy and knowledge exchange.

The opportunities promoted by this SIA align with Brunel University London's strategic priorities as set out in its long-term vision, Brunel 2030.[23] The SIA connects with its research strength in design, environmental forensics, engineering and science, sustainable construction, energy efficiency, big-data and artificial intelligence, urban planning and design. Brunel has an excellent track record for the successful delivery of innovative industry – university projects, in fact its Engineering and Design capabilities are ranked amongst London's biggest and best. It also has areas of research strength in food distribution, where it leads a prestigious RCUK National Centre for Sustainable Energy Use in Food Chains with 33 industrial partners, and in advanced casting technologies for light-weighting applications in the automotive and aerospace sectors; here, Brunel and partners JLR and Constellium are developing a unique national scale-up facility for aluminium and magnesium casting and processing supported by EPSRC, HEFCE UKRPIF, Innovate UK and a basket of industrial funding.

Royal Holloway has considerable strengths for innovation relevant to the economy of the Airport and was ranked 17th in the UK, 126-150 in the World for computer science (2018 Times Higher Education World University Rankings).[24] The Information Security Group (ISG) is world renowned for its expertise in cyber security which is increasingly important for a modern digitally connected transport hub. Endorsed by GCHQ, the ISG supports both established industry and start-ups in the cyber security industry. The Computer Science department, ranked 8th in the REF for outputs and joint top for environment (4* and 3*) has a long history of leading the UK in machine learning and artificial intelligence and has now a substantial research capability in the area of big data. The Department of Psychology, ranked 4th overall in REF2014, works with the airport on traffic and road safety issues. Four of Royal Holloway's social sciences departments were ranked in the top ten in REF2014.

The University of Surrey is a world-class, research-led university committed to research excellence. Their research seeks to answer global challenges, drive innovation and deliver real-world impact. 98% of Surrey's research is classed as world leading, internationally excellent or internationally recognised. In particular, Surrey is a world leader in 5G technology; its 5G Innovation Centre brings together academics and industrial partners to develop the infrastructure that will underpin the way we communicate, work and live in the future.

The University of Reading is focused on understanding and adapting to global challenges, as well as striving to secure the common-good, the diversity of human culture, and the value of the arts within society. REF 2014 confirmed the University of Reading's place as a world-leading research-intensive university; 98% of University of Reading research is internationally recognised, and 78% of our research is classed as internationally excellent. 27% of our research is world leading. Reading has a number of strengths in environmental sciences, construction and the built environment that support the creation of sustainable airports.

Although some 20 miles outside of the study area, the new £65 million Digital Aviation Research and Technology Centre (DARTeC), which will be built at Cranfield University, will provide digital aviation technology research facilities unprecedented in Europe.

Our consortium partner BRE, is a world leading multi-disciplinary building science centre with a mission to improve the built environment through research and knowledge generation.[25] Their £10M per annum research portfolio spans materials, full scale structural

performance, sustainability (including energy, waste efficiency), fire, security, safety, smart building technologies and the impact of indoor environments (noise, temperature, air quality, lighting etc) on health and wellbeing. They are also currently funding 25 PhD studentships and supporting a further 75 through its strategic partnerships with other institutes in the UK and abroad. In the last 2 years over 5000 individuals have graduated through BRE's online training portal targeting professionals and those in full time education.

The BRE Innovation Park features over 300 construction innovations and emerging technologies being evaluated and attracts thousands of visitors from around the world every year. BRE also provide globally recognised testing **(**the performance of materials, products, systems and buildings) and certification **(**people, products, and whole systems). This also provides a valuable conduit with the supply chain via its Constructing Excellence best practice programme, identifying challenges in current provision which can be supported by future research and skills development.

As recognised in the Industrial Strategy White Paper,[26] 'innovation is a highly collaborative activity which flourishes in clusters and networks' and this is demonstrated within our study area. The four universities around Heathrow jointly produced over 500 research outputs in the last decade, and Brunel is one of the Building Research Establishment's most established university partners. The region also supports a range of high-profile innovation projects, for instance Royal Holloway and Brunel are developing a project on audio-visual digital creativity using Heathrow as a test-bed.

2.2 Innovation Strengths and Growth Points

Within the study area, Heathrow is a major innovation strength and economic growth point. It is the anchor business for more than four hundred businesses, employing 76,500 people, and makes a unique contribution to the local innovation landscape

- Helping to identify 'technological domains' for commercial exploitation
- Delivering Value Creation and Value Capture Activities via their business networks
- Acting as a magnet for SMEs who wish to access wider business networks

In February 2017, Heathrow Airport Ltd launched Heathrow 2.0, its plan for sustainable growth. As well as providing a strategic approach to the sustainable development of Heathrow, the plan recommended establishing a Centre of Excellence at Heathrow which has begun providing industrial and research organisations with research and demonstration opportunities with and on the airport. The Case Study Proper Oils illustrates how airports can support innovative businesses to grow, especially when they share sustainable business agendas.

Case Study - Proper Oils

Proper Oils delivers, collects and recycles cooking oil from catering customers across London and the South East. Customers number over 2,000 and include Heathrow Airport, Wembley Stadium, Camden Market, and restaurant chains like Hawksmoor and Barrafina. They have been growing at 50% year on year for the past 3 years, supported by a focus on sustainability and innovation. Heathrow's relationship with this SME has supported their own sustainability goals on carbon and waste, as Proper Oils have achieved accreditation and demonstrated best practice to minimise their own impact and deliver outcomes for their customers. Examples include:

- Freight Operators Recognition Scheme accreditation since 2008 – this proves our transport operations work to best practice. As part of this we monitor our fuel usage
- Zero waste to landfill company for 8 years
- Becoming a London Living Wage Employer over 3 years ago
- Using 100% renewable electricity for the past 2 years – supplied by Good Energy
- Becoming the first cooking oil delivery, collection and recycling company to become carbon neutral. In 2016-17 we removed a total of 152 tonnes of CO_2e.

Showered with a host of awards and green accreditations, Proper Oils demonstrate that a focus on sustainable airports can lead to innovative businesses supporting sustainable cities.

At a national level, the UK has the biggest aviation market in Europe and the second largest in the world, with London having the busiest airport system of any city in the world. The prosperity of the UK is critically dependent on the health of the UK aviation sector. Aviation adds £52 billion to the UK's GDP, supports substantial inward investment and almost one million jobs[27].

Many multi-national firms invest in Britain because of our aviation network,[26] with airlines competing to give the customer a wide choice, making for cheaper and more efficient mobility of people and cargo. The UK government is continuing its work to develop a new strategy that will ensure that UK aviation remains a global leader.

In addition to Heathrow the region also contains a number of innovation clusters. For instance the Thames Valley digital technology cluster comprises 7,800 digital technology companies, the highest concentration in the UK, employing 56,300 digital technology specialists and generating 600 new start-ups per annum.[28] The region also benefits from the presence of the Transport Systems Catapult and the Transport Research Laboratory, both involved in research, development and innovation in intelligent mobility.

The Slough Trading Estate, at the Eastern end of the region, is owned and operated by SEGRO. This is the largest industrial estate in single ownership in Europe, which consists of 486 acres of commercial property providing 700,000m^2 of accommodation to 500 businesses and a working population of about 20,000 people. There are 23 data centres on site, the largest data centre cluster in Europe. SEGRO also operates the Heathrow Cargo Area to the south of the airport.

3 Sustainable Airports as drivers for growth

The UK and the world need sustainable airports. The opening paragraph of the UK Aviation Strategy document (April 2018),[29] illustrates this well:

"More of us are flying than ever before. Passenger numbers have increased by over 20% in the last five years with 268 million passengers passing through UK airports in 2016. Passengers are benefiting from the opportunities presented by more connections, cheaper flights and greater choice and demand looks sets to continue. Our latest forecasts show that [UK] passenger numbers are likely to increase to 410 million by 2050. This growth is good news for the thriving aviation sector and for the UK economy, but brings with it challenges that need to be addressed."

In this section we discuss the generic issues associated with the size and trends in markets created by sustainable airports, and our study area's capacity for exploiting those opportunities. In the following 4 sections we go on to study the specific issues associated with our four technological themes in more detail.

3.1 National and International trends and size of global markets

There are 42,000 airports across the world and that number is continuing to grow. The global aviation industry is growing significantly with the International Air Transport Association predicting a near doubling of air passengers from 3.8 billion in 2016 to 7.2 billion passengers in 2035.[30] Research, innovation and business collaboration are critical to achieving growth on a sustainable basis. Over the last decade growth in global aviation has been both strong and steady, with an average increase of 5.5% per year in worldwide revenue passenger kilometres. Similarly, air passenger volumes have grown by an average of 6.7% and air freight demand is growing by 8.8% per annum. Worldwide, air transport supports 63 million jobs, underpins 3.5% of the global economy and transports 1/3 of all world trade, £13.5bn worth of goods per annum.

The UK industry body Sustainable Aviation identifies a number of sustainability goals for the aviation sector including:[31]

- Developing a competitive aviation industry that makes a positive contribution to the UK economy,
- Meeting the needs of society for air transport, whilst maintaining constructive relationships with stakeholders,
- To reduce UK aviation climate change emissions, the impact of aircraft noise and to work in partnership to improve the air quality around airports.

At a strategic level, these goals identify the technological challenges associated with making the aviation sector more sustainable, as well as highlighting the overlap with the Industrial Strategy. The Case Study on TURBOGAS illustrates how innovation linked to sustainable airports can attract investment and create business growth.

Case Study - Clean Sky project TURBOGAS

The Clean Sky project TURBOGAS was carried out by a team formed by ENVISA (a French R&D SME based in Paris) and Brunel University London in reply to the call for proposals for the Clean Sky topic "Advanced Turbofan Engine Emissions Model" (short-named TURBOGAS), led by Thales. The ENVISA team has been working in the field of aviation environmental impact modelling for more than twenty years and participates in international expert working groups (such as the ICAO Committee for Aviation Environmental Protection). The team at Brunel University London was composed of highly skilled software developers with experience on aviation environmental modelling.

The proposed model was structured around a series of modules. A specific module was in charge of the thrust to fuel flow conversion, taking into consideration both operational and procedural parameters (aircraft speed, flaps configuration, corrected net thrust, etc), as well as the ambient conditions along a flight trajectory. Another module focused on the corresponding emission indices adjustments. Fuel flow and emission indices for various discrete points along an entire trajectory were then aggregated in another module to calculate the total fuel burnt and the emissions of CO_2, NO_X, H_2O, particulates, etc. The thrust to fuel flow conversion and the emission indices adjustment algorithms were based on the latest methods developed by the ICAO working groups or from the SAE standards, in order to ensure a robust validation of the model. Finally, the water emissions were coupled with operational and meteorological parameters to estimate the condensation trails occurrence and lifetime. One of the many advantages of this modular approach is that a single module can be updated with the latest methodological advances without modifying the rest of the software.

3.2 Local Science and Innovation Talent

Our study area is fortunate in having a low fraction of employees with no qualifications[7], and high fractions of the working age population (38%) qualified to NVQ 4+, compared to the rest of England outside London, where the average is 34.5%.

Of residents employed in science, research, engineering & technology[8], 52.25% are qualified at NVQ 4+ compared with the national average of 43.50%. Residents in this employment sector with no qualifications are 3%, compared to the national average of 4.9%.

In addition, the research-intensive universities clustered around Heathrow to the west of London include substantial numbers of graduates, particularly with STEM qualifications.[20]

	2014/15	2015/16	2016/17
Total Graduates	17,951	19,435	21,096
STEM UG Graduates	3977	3882	4200
STEM PGT Graduates	492	524	803
STEM PGR Graduates	599	613	578

The percentage of the total workforce employed in science, research, engineering & technology professions[8] is 9.0% compared to the national average of 5.6%, which contributes to the higher productivity of the study area. The recognition of overseas qualifications is an important issue in this study area, where there are areas in which over 50% of the population were born outside the UK. There is also an undersupply of apprenticeships, with the fraction of young people going on from school into an apprenticeship being half the national average. This is an issue that a number of the universities and FE Colleges in the study area are looking to address. The Heathrow Skills Taskforce, chaired by Lord David Blunkett, is working to develop a clear plan to for the airport's education, employment and skills strategy.

This SIA study area also has particular recognised hot-beds of talent. Berkshire for instance has the largest tech talent pool outside of London, and has nearly 8,000 tech companies and 56,000 tech specialists[32].

3.3 National and International Engagement

In support of its expansion plans, Heathrow has created a 9-point plan to connect the UK,[33] bringing opportunities to trade with the world (Figure 3). This also usefully illustrates the multi-modal connectivity of our study area with the wider UK, and Heathrow's role as a connectivity institution.

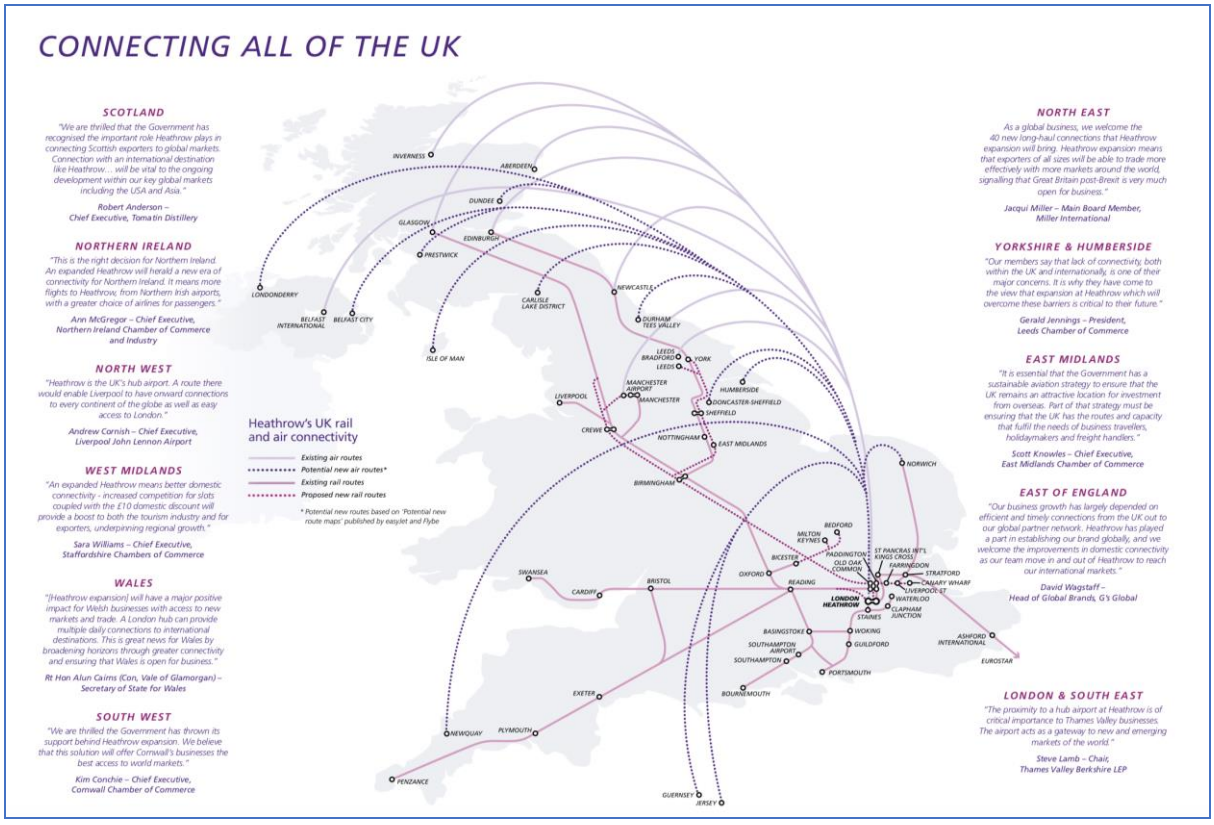


Figure 3: Heathrow's multi-modal connectivity to the UK[34]

3.4 Developments in the wider funding landscape

There is strong synergy between the themes of this SIA and the Grand Challenges in the Industrial Strategy 2017, which aim to put the UK at the forefront of the industries of the future. There are direct links between our themes of Big Data and Cyber Security and Intelligent Mobility and the Industrial Strategy Grand Challenges of Artificial Intelligence & Data Economy and the Future of Mobility. The Industrial Strategy Grand Challenge of Clean Growth intersects with airports through concepts such as Smart New Materials, Low Carbon Construction, Sustainable Transport Systems, Embedded Circular Economies and Clean Energy Solutions. Airports are addressing the challenge of an Ageing Society through developments in Human Centred Design, Accessible Transport Solutions and the Inclusive Customer Experience.

These synergies with the Industrial Strategy will help to support the SIA's recommendations and link with the wider funding landscape. In addition the SIA mirrors the Industrial Strategy, Building a Britain fit for the future, in seeking to:

- Place UK airports and their supply chains at the forefront of the artificial intelligence and data revolution.
- Ensure UK airports are world leaders in the way people, goods and services move.
- Maximise the advantages to UK airports and their suppliers from the global move to clean growth.
- Support UK airports to innovate to help meet the needs of an ageing society.

The UK Government has committed £1.95bn[35] through the Aerospace Technology Institute[36] for match funding aerospace R&D through to 2026. In addition, a competition launched in December 2017 by Department for Transport is supporting the development of low carbon fuels for aviation and freight.[37]

4 Sustainable Construction

Development at Heathrow has taken place over the past 70 years, building out from the original post-war airfield to its present substantial estate. With two runways, tens of miles of taxiways and many hundreds of buildings, maintaining the infrastructure in a safe operating state, whilst driving increased efficiencies within a tight environmental footprint, is an on-going challenge for Heathrow, and its supply chain responsible for these activities.

Hence the construction and operating environment presents a range of constraints, some of which are unique to Heathrow. These provide the stimulus for innovation that generates new solutions, and opportunities to test new technologies that could be applied to construction and infrastructure projects globally.

The Heathrow construction contractors, as a team, work to a common framework of 'Realising the Benefit', and share innovation and best practice through an internal innovation portal. This has led to both Heathrow and the supply chain working collaboratively, for the benefit of all businesses.

4.1 National and International trends and size of global markets

The trends in sustainable construction provide significant opportunities to develop and improve construction and maintenance of airports. These trends include

- materials that provide added performance – such as durability and light-weighting
- modular construction materials and onsite assembly
- replacement materials that are inherently more sustainable, for example to reduce carbon in sourcing or transport, or are 'renewable'

In addition, there is increasing trend for clients to use 'output specifications' which provides an innovation opportunity that working to established standards does not. Standards require compliance with established methodologies and use of specified materials. Using output specifications allows the supplier to develop novel materials and techniques, but that nonetheless meet an agreed level of performance.

There are currently over 400 major construction projects going on at airports worldwide, with between 20 and 30 new airports under construction.[38] It is estimated that £1trillion in airport infrastructure projects are planned or under way[39] within a timescale that continues (in some extreme cases) for four decades into the future. These range from new terminals on green field sites, to new runways, terminals, pier or satellite extensions and refurbishments.

4.2 Local Science and Innovation Assets

Strengths in the local ecosystem that support sustainable construction at airports include

- BRE (Watford) – leading on sustainable construction, standards and innovative materials for construction of buildings, their performance, resilience and efficiency
- Brunel University London and the National Structural Integrity Research Centre focussing on building structure and materials
- The University of Surrey's Centre for Environment and Sustainability is internationally renowned for its environmental engineering research.
- A variety of businesses in the study area developing innovative solutions for smart signage, infrastructure and lighting, for whom Heathrow is an innovation partner, such as Bright Green Technology Ltd (Byfeet) and Trueform Engineering Ltd (Hayes).

BRE worked in collaboration with Heathrow to develop the first bespoke standard for airport terminals to assess, and recognise and encourage construction sites managed to reduce resource use, energy consumption and pollution. Terminal 2 was the first airport terminal to undertake and achieve the new BREEAM (BRE Environmental Assessment Methodology) assessment. This was achieved through building initiatives such as recycling over 90% of construction waste and design innovations such as the fire sprinkler system incorporated in the fire protection system which will save 300,000 litres of potable water per year by recycling test water.[40] This BREEAM standard for airports has now been used across the UK, France, Norway, Finland and the Netherlands.

4.3 Local Science and Innovation Talent

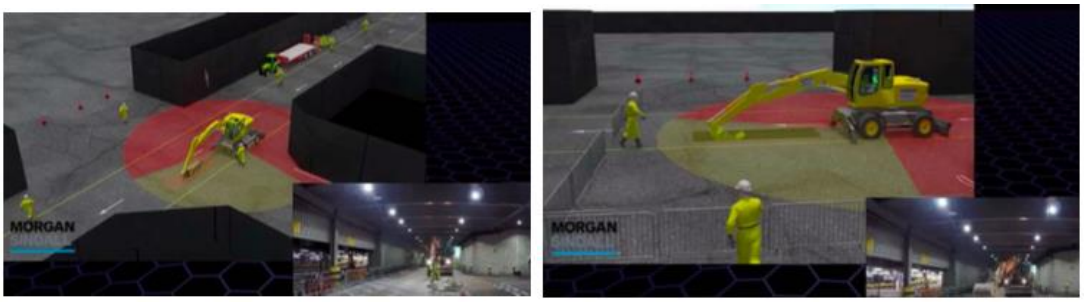
Heathrow and its supply chain have developed specific skills and talents for working at the airport, including[41]:

- monitoring via dashboards of energy performance of systems, leading to optimisation through control systems, and infrastructure investment
- airside management on pavement condition monitoring and repair
- management of noise and wider environmental performance in construction activities
- new approaches to engage workers to support safe and efficient working
- supply chain partnering over the long term, with a 'One Heathrow' approach to innovation, across *Airside* and *Landside.*

The operational demands of airside construction and maintenance require the supply-chain workforce to have specialised training and to be highly competent to work safely and effectively. Our Case Study, the use of Virtual Reality (VR) and Augmented Reality (AR), illustrates innovation in the delivery of training and skills development.

Case Study - Use of Virtual Reality (VR) and Augmented Reality (AR) technologies

Plant People interaction is still a leading cause of site incidents and accidents. Constrained working environments such as 'airside' present particular hazards to the operatives including proximity of adjacent buildings, use of 360 excavators and night-time working, compounded by tight timescales between operational use. Being able to practice the operation ahead of delivery is a new concept that can bring significant benefits in delivering the work, and in this case aim to remove unnecessary Plant People Interfaces.



Airside contractor Morgan Sindall's approach was to use VR environment to create a *Visual Mission Statement.* By bringing in 4D Mission Room technology to Heathrow, the Morgan Sindall team host workshops with the work team, review the tasks as outlined in the animation and identify any unnecessary interfaces, risks or issues. Revisions are made and the final animation is used to define the job.

4.4 National and International Engagement

To help facilitate their innovation 'pull' Heathrow is an active member of the 2Degrees Innovation Gateway,[42] through which they can set challenges for national and international SMEs to respond. The sustainability focus has been on energy, waste and water management, all critical elements of the management of sustainable airports. This has led to a range of innovations and trials of equipment that continually improve environmental performance and realise wider benefits, including costs and improving safety. Heathrow and its main contractors also share innovation learning with the wider UK industry through the i3P platform.[43]

4.5 Developments in the wider funding landscape

Innovate UK are investing up to £72M to establish a Core Innovation Hub (CIH) to transform the UK construction sector.[44] The core innovation hub will support collaboration across the digital, manufacturing and construction sectors to develop and commercialise digital and manufacturing technologies for the construction sector. The activities of this hub will connect with business and academia and will clearly have relevance to sustainable airports.

The Industrial Strategy Challenge Fund for Transforming Construction has also recently been launched, with £170M to move the construction industry towards a 'manufacturing approach.' Mike Potts, Interim Challenge Director, blogged "Picture a future where all UK built infrastructure was delivered faster and cheaper through modern manufacturing supply chains and onsite robots."[45]

The Logistics Hubs proposal which is being developed by Heathrow Airport Limited is at the leading edge of this manufacturing approach to construction.[46] UK firms are frequently involved in major airport construction projects all over the world, although all too often this involvement is restricted to the design phase of the project. The development of a modular, off-site, manufacturing approach to work at Heathrow increases the prospects for further work using this approach for the UK supply chain at other airports worldwide.

Case Study - Logistics Hubs

Logistics Hubs are identified in the Government's Industrial Strategy as a key mechanism to share the benefits of infrastructure development around the UK, by developing skills and creating conditions where successful businesses can emerge. Heathrow Airport announced that Logistics Hubs will participate in off-site construction of the new runway and associated infrastructure (subject to the decision on expansion), mitigating the impacts of construction on communities around Heathrow and spreading economic benefits across the UK (worth £30bn).

The hubs will develop as 'offsite' construction environments that will manufacture the components necessary for onsite assembly. Heathrow has also begun working with other major infrastructure companies to explore how the final sites could be used for future projects. The planned expansion programme has the potential to drive innovation in materials and construction systems, enabling key sets of components to be manufactured efficiently on specialised sites, to then be collected when needed and assembled on site at Heathrow. Simple modular components eases management and maintenance, whilst the design focus also brings in the opportunity for new materials to reduce carbon in the build and operation. Through Building Information Management (BIM) technology, resilience can be evaluated and built in, for example the location of electrical and IT services to support future retrofitting or changes to building configurations. The overall approach aims to reduce costs significantly by giving security to the supply chain, whilst delivering the environmental performance expected of Heathrow's sustainability strategy Heathrow 2.0.

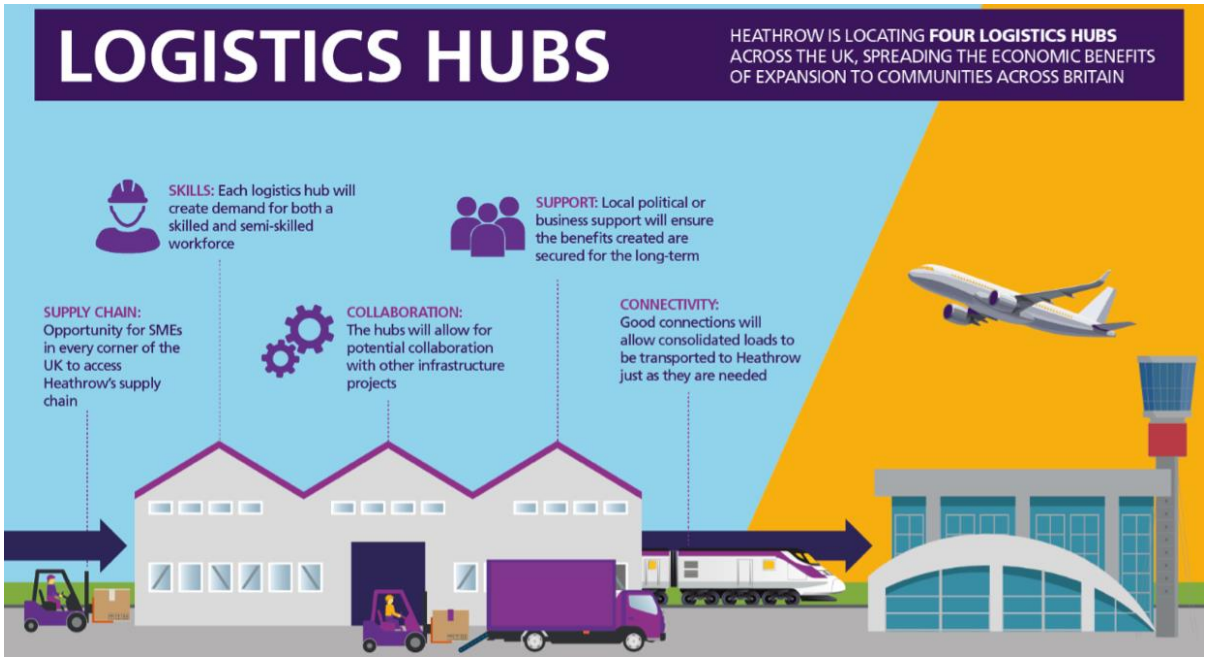


Figure 4: Heathrow Logistics Hubs[47]

5 Big Data and Cyber Security

The wholesale adoption of digital technologies has led to rapid expansion of the big data and cyber security industries. These enabling technologies support increasing digital interconnectivity and dependency within airport operations, leading to airport specific market opportunities.

This theme has links with the earlier Innovation South SIA[48] which has an overlapping geography and partners. The Innovation South SIA illustrated the role of big data and cyber security as enabling technologies for a range of sectors including marine and maritime.

Airlines and airport operations centres handle terabytes of data on a daily basis. Furthermore, the proliferation of connected devices, such as the Internet of Things, has led to an exponential increase in data. Today's computing power has enabled innovations which utilise this data to increase safety, security and efficiency for all stakeholders. Coupled with machine learning and predictive analysis, a new global market is swiftly growing for manufacturers, airlines, service providers and consultants. Moreover, promises of significant cost savings through better fuel economy and minimisation of delays are driving big data investment. Significant plane and passenger traffic at Heathrow mean the opportunities to grow, experiment and innovate at Heathrow and then export to airports worldwide are huge.

Aviation faces unique cyber security challenges due to embedded proprietary systems not designed to handle sophisticated threats, and airport modernisation which widens the threat landscape. The multi-stakeholder environment presents challenges, and there are opportunities for new export markets for cyber security services and solutions. Emerging national, regional and global standards enhance such opportunities, particularly for innovative organisations whose developments facilitate compliance.

Increasing use of big data means that malicious damage presents an increased risk to airports, so developments in cyber security needs to track innovations in the use of big data. Similarly, big data analytics and machine learning provide threat intelligence to cyber security solutions, a market which is growing considerably.

5.1 National and international trends and size of global markets

A number of mega-trends are driving the need for increased cyber security. These include the digitisation of everything, data protection and the increase in cyber criminals and hostile state actors exploiting vulnerabilities in apps, devices and platforms.[49]

Global spend on cyber security products is expected to exceed £700 billion cumulatively from 2017 to 2021.[50] According to SITA Air Transport IT Trends Insights 2017, global airport spend on cyber security and cloud services reached $33 billion. This figure is expected to be similar in 2018 or higher.

Results of a sectoral analysis survey (August 2017) to assess the total size of the UK Cyber Security market will be published soon.[51] Statista estimated the market to be worth £3.4bn in 2017[52] and forecasts exports rising to £2.6bn by 2021.[53] The SITA Air Transport IT Trends

Insights (2017)[54] report states that 96% of airports surveyed are planning major programmes of Cyber Security investment and Cloud Services over the next 3 years.

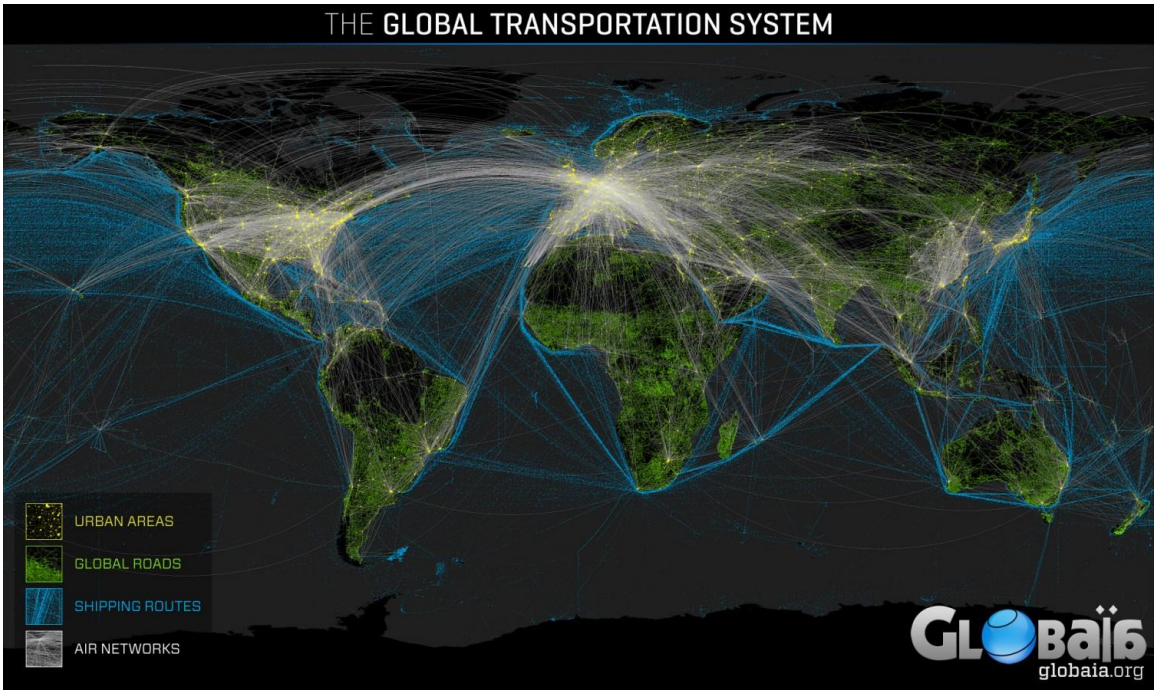
In 2016 the Government published an updated National Cyber Security Strategy (2016–2021).[55] The strategy is supported by £1.9bn of transformational investment and it sets out ambitious policies to protect the UK in cyber space. Published in March 2018, the UK's Cyber Security Export Strategy[56] will help UK cyber security companies showcase their capability to find and secure export opportunities.

Various big data forecasts focus on different growth areas. Technavio's market research[57] predicts the global big data services market will grow at a compound annual growth rate (CAGR) of above 24% from 2017 – 2021. Another report by Grand View Research in December 2016[58] states the total global big data market could reach £93bn by 2025. Research undertaken by the Centre for Economics and Business Research, on behalf of SAS, put the *cumulative* value of big data and the Internet of Things at £322bn for the UK market from 2015 – 2020.[59]

The UK's aviation sector recognises the value of data and a range of responses were made to the government's call for evidence encouraging steps to make more aviation-related data open and transparent.[60] These trends are set to continue with matched commercial benefits.

Case Study - Global Supply Chain Optimisation project GEMSTONE

The GEMSTONE project has been completed in collaboration between Brunel University London, Caterpillar and Intel. The project focused on Global supply chain modelling and investigation of various triggers such as path trajectories, combined use of aviation and nautical routes, impact of environmental parameters and environmental tax on structural modifications of supply chain. The investigation has been carried out in the context of efficiency and adaptability of AI optimisation algorithms on combination of multiple objectives and its performance markers in terms of reaching the optimisation goal and its performance in real-time evaluation environment. The investigated scenarios included use of aviation routes only, use of combined routes, and the ecologically friendly supply chain. The environmental impact was measured using CO2, the minimisation of transportation and communication routes in supply chain network (from length and time perspectives). One of the advantages of the developed approach was the ability to solve small and large supply chain optimisation problems, with real-time evaluation constraints, without any modifications in its structure or implementation. The multiple objectives can be combined and various scenarios can be evaluated using the same developed optimisation module.



5.2 Local Science and Innovation Assets

Several organisations within our study area have specific strengths in big data and cyber security for aviation. The strong digital economy in the vicinity includes a high density of notable corporate companies, SMEs and universities offering innovative solutions which together provide compelling big data and cyber security offerings.

The range of corporate companies in the study area include Thales who boast over 2,000 Cyber Security specialists, protection for 80% of the world's banking system and 5 Cyber Security operation centres. Their Reading office is the headquarters for their research and technology activities. Helios aviation consultancy (Hampshire) has specific expertise in

airport Cyber Security, along with the related standards and policies, and led the major SESAR Cyber Security study "Addressing Airport Cyber Security" in 2015.[61] Sophos (Abingdon) has been recognised as a leader by Gartner for many years in their Magic Quadrant Report for Endpoint Protection Platforms.[62] Blackberry Software (Maidenhead) has achieved the highest score on several occasions by Gartner for its high-security mobility management software.[63]

In addition, Heathrow and many other airlines and airports have worked with SITA, which is positioned as the world's leading specialist in air transport communications and information technology.[64]

The Digital Catapult supports and promotes digital innovation in the UK. Their focus is on artificial intelligence, augmented and virtual reality and future networks such as 5G.

Brunel University London has considerable strengths in the digital economy, where it was ranked 5th in the UK by the Witty report,[65] and in human centred design. The Human Centred Design Institute at Brunel performs research leading to products, systems and services which are physically, perceptually, cognitively and emotionally intuitive. Work on the Automotive Habitat Lab[66] sponsored by Jaguar LandRover, has developed a real-time data link between an automobile and a control room. Beyond the data link and software, the project has also developed emotion driven test scenarios[67] (Weber et al. 2018) and a psychologically-grounded co-design protocol for use between the automobile occupants and the control centre design staff. This has translation potential for airports: an Airport Habitat Lab could assist the discovery of experiential, psychological, sociological, behavioural and ethical aspects of new airport product and service concepts, including big data and cyber security.

Case Study - Data communication in airports, the Stardust project

The **Internet of Things (IoT)** is rapidly emerging and the number of connected devices is expanding exponentially. We are evolving towards a hyper-connected world, in which almost unimaginable numbers of devices, sensors and smart objects may be connected 24/7 in a digital world. In this landscape, the introduction of LEDs has instigated a paradigm change for high efficient lighting systems (i.e. ***solid-state lighting (SSL)*** *or LEDification, i.e. Lighting 2.0*), the entire lighting market is going through a radical and incredibly fast revolution, where the development of smart lighting solutions (*smart lighting, i.e. Lighting 3.0*) is being pushed beyond the limits of simple intelligent systems with the idea of creating interactive SSL luminaires able to provide hubs for data communication into a building as well as self-commissioning control systems offering new services going beyond simple illumination (*IoT lighting, Lighting 4.0*).
IoT integration into lighting infrastructure is on the horizon, and Brunel University London is researching at the cutting edge. Wi-Fi security weaknesses & privacy will be a key constraint and challenge. The Stardust project proposes a completely new device & technology to allow an efficient (low power consumption), broadband, multicast, miniaturised, cost effective, secure and safe light communication solution. An innovation which would align with sustainable airports.

Both Royal Holloway University of London's Information Security Group and the University of Surrey's Centre for Cyber Security have been recognised as one of the 14 UK Academic Centres of Excellence in Cyber Security Research (ACE-CSRs) by the National Cyber Security Centre and the Engineering and Physical Sciences Research Council. The research at Royal Holloway has a strong focus on the security of systems and technologies[68] whereas that at Surrey addresses privacy and data protection, secure communications, and human-centred security.[69]

Slough Trading Estate, owned by SEGRO, is the largest data centre cluster in Europe with 23 facilities on site. It boasts circa 2 million sq ft of accommodation and fibre-optic connections to Europe and the US. It provides a high security environment, outside of the Central London risk zone, the Thames Valley flood plains and flight paths and has industry-leading security, strong enough for the US Government.[70]

5.3 Local Science and Innovation Talent

The Thames Valley digital technology cluster comprises 7,800 digital technology companies, the highest concentration in the UK, employing 56,300 digital technology specialists and generating 600 new start-ups per annum. Cyber Security and Big Data specialisms are in high demand however, exceeding the available talent pool.

10 miles east of our study area, the London Cyber Innovation Centre,[71] a new £13.5M cyber innovation centre in the Queen Elizabeth Olympic Park, will spur the development of cutting-edge technology and help to develop new talent through up to 2000 UK jobs in cyber security. Start-ups chosen for the scheme will work with large firms as they identify cyber security challenges critical to their businesses. The centre will offer a tailored programme of support to at least 72 companies over three years and is open to firms from across the UK. Other start-ups not on the programme will also be able to access the centre's support and facilities.

The Gemstone Case Study demonstrates how the application of real-time data solutions to complex supply chains can achieve global efficiencies which deliver huge productivity gains and demonstrable competitive advantage.

5.4 National and International Engagement

Trade bodies, institutions and governments have recognised the challenge of cyber security and placed it firmly on their agenda. The industry at large has recognised greater collaboration and data sharing is required to effectively combat threats, and take advantage of the enabling technology opportunities. Regions with fine-tuned innovation strategies and investments will likely lead transformational change with economic benefits to match.

Presentations and representation at the **ICAO Cyber Summit and Exhibition - Making Sense of Cyber** (April 2017)[72] confirm international industry awareness. The second aviation Cyber Security Summit is scheduled for November 2018, at the Royal Aeronautical Society. The UK National Cyber Security Centre and the UK Department of Transport have presented at these and other international events.

Governments and national security bodies worldwide have recognised the need to update standards given that airports form part of their critical national infrastructure. NCSC was involved in creating the Eurocae standard ED-201 for Aeronautical Information System Security Framework Guidance.[73] The Health and Safety Executive also published guidance for Cyber Security on Industry Automation and Control Systems,[74] which is directly applicable to Airport Operation Centres.

Commercial opportunities undoubtedly exist to develop innovative tools and applications to help compliance and develop UK exports.

5.5 Developments in the wider funding landscape

The Future Aviation Security Solutions (FASS) programme[75] aims to improve aviation security by funding and supporting the development of innovative science and technology. The programme has £25.5M to invest over 5 years.

More broadly, following the Industrial Strategy, there are multiple funding opportunities for projects in AI, big data, cyber security and the digital economy through the industrial strategy challenge fund.

There is also an untapped potential to look at Heathrow as a SMART City and build links with the Future Cities Catapult. Given the scale and complexity of an airport the size of Heathrow it has many of the elements of a city, but within a considerably more controlled environment to allow prototyping and demonstration of solutions.

Case Study - Semantic Models and Baggage Intelligence

Aviation ecosystem partners want to transform the aviation industry to enable easy information sharing that enables improved decision making and profitable innovation for the immediate airport community and UK Plc.

Heathrow Airport Limited has developed a product, known as the ACI ACRIS Semantic Model that reduces the barriers to entry for new IT start-ups and small companies that create innovative IT solutions. This product enables the rapid development and commercialisation of innovative software solutions with minimal resources and supports the development of a community of IT businesses in the immediate and wider areas around the airport.

New IT start-ups in the Heathrow local community can use these models to create what are known as minimum viable software products in weeks, as opposed to months and years, which makes them more productive and highly competitive in the context of Brexit. This also enables these start-ups to easily attract investments. Two companies, Ultra and Rockport use the models to deliver projects worth over £2M to various clients including Heathrow Airport. Rockport Software worked with Heathrow's Information Architect to develop the baggage domain part of the ACI ACRIS Semantic Model and used this as the basis for the design of a baggage business intelligence system.

A growing number of organisations are now using the ACRIS Semantic Model including Ultra Electronics and ARUP, Rockport, Apple, Google, Locuslabs, SITA and many airports. The ACRIS Semantic Model could be exploited further if a service model with supporting infrastructure was developed around it.

6 Operational Excellence

Heathrow is the largest hub airport in Europe, with 476,000 aircraft movements annually[76]. As a hub, Heathrow has driven efficiency across all aspects of its operations to ensure that passengers and their luggage meet the connecting flights, and that impacts for European airspace are minimised. As the world's most efficient 2-runway airport, it is viewed as an exemplar in the 'industry', because of the systems, processes and culture that support its daily operation.

Figure 5: West London Business: HEATHROW TODAY: BRITAIN'S FRONT DOOR[77]

6.1 National and International trends and size of global markets

There are significant trends within the sector, amplified at Heathrow, enabled by the air traffic management (ATM) and digital revolution. This is leading to 'game changing' developments within ATM unlocking Heathrow's readiness to service the Civil Aviation Authorities transformation of the UK's airspace into a new digital airspace. This in turn means that more aircraft movements and accurate scheduling can be envisaged at airports. Major new ATM initiatives such as "Arrive on Time" will deliver tangible benefits for both the passenger and the local communities and will revolutionise the operational procedures for arriving flights into Heathrow. Advances in aircraft technology provide improved efficiency in engine emissions, and reducing the noise envelope of the airport. Innovations that integrate the many data-streams at the airport are enabling the movement of people, luggage and aircraft to be optimised.

The global airport operations industry generated revenue of about $152 bn in 2015, according to Airports Council International (ACI). Industry growth is expected to come from

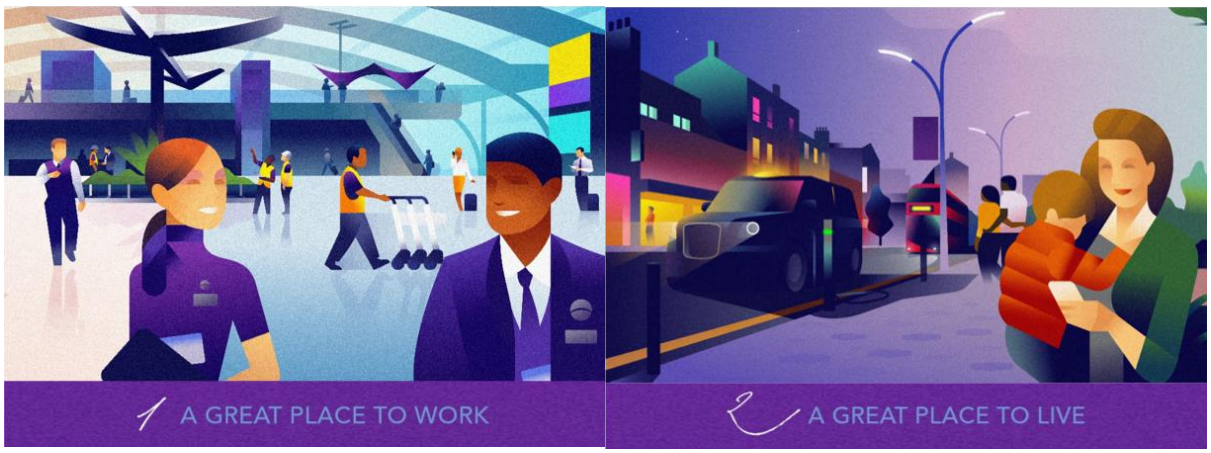
airports located in the emerging markets of Asia/Pacific, the Middle East, Latin America, and the Caribbean.[78]

6.2 Local Science and Innovation Assets

Heathrow has an inhouse ATM team whom actively participate and shape the EU agenda and future legislation. This position is also strengthened via their legal binding consortium agreement with 11 other EU airports known as the Single European Airport Consortium (SEAC). Through leading the way in ATM R&D Heathrow continues to work with partners in systems developments, as well as the contractor/supplier base in the UK and internationally. Specific strengths include:

- Pioneering time based separation of aircraft (as opposed to distance based) , in partnership with NATS.[79] Heathrow will also be introducing performance based navigation and airport response;
- Operating standards for airspace and airlines; Being the single UK airport since 2012, to deploy Airport Collaborative Decision Making (ACDM) procedures;[80] 5th European airport;
- Environmental sustainability – including adaptation to a changing climate;
- Regulatory environment and innovative measures to exceed targets, including noise monitoring and management;[81]
- Proactive community engagement and support for community initiatives;[82]
- Enhance operational forecasting, planning, situational awareness and performance review, through adopting big data and machine learning techniques to prediction flows and enable proactive operational decision making;[83]
- Development of advanced Airport Operations Centres (APOC) to co-ordinate and control the airport operations;[84]
- Operating culture: Team Heathrow[85] – Making Every Journey Better, to enable our ambition of “Happy passengers, travelling with their bags, on time”.

Heathrow 2.0, the plan for sustainable growth, sets out a range of goals and measures being taken to deliver improved environmental performance and sets Heathrow as a leader on this issue.[86] Each of the four ‘pillars’ of this plan align to embed improving environmental performance as the operating culture.



Underpinning the plan is the development of an innovation centre that will drive future research and technology developments to support the sustainable airport operations.

Given the significance of the noise impacts in the locality, Heathrow has made significant investment to become an innovation leader that understands, and manages the noise envelope across the estate, and in the surrounding communities. The Noise Action Plan (NAP) sets out proposed actions to enable Heathrow to operate within defined limits,[87] and work closely with the community on a range of interventions. The range of measures and assessments have set Heathrow apart in this expertise area with transferable knowledge for other airports and sectors.

6.3 Local Science and Innovation Talent

The University of West London delivers employer focussed Airline and Airport Management Degree and Masters courses, helping to grow local talent for Heathrow and other airports.

BRE already has active engagement with a number of airport developments in the UK and abroad through its technical capabilities supporting the design, build and upgrade stages but is also now engaging with ongoing operational efficiency improvements in relation to indoor environment monitoring (temperature, noise, light, air quality etc) and resource efficiency (energy, water, waste). Significant validation and development of tools which evaluate and improve the operational efficiency of sophisticated highly controlled mixed use developments in retail and health development are being applied to airport environments.

Heathrow has itself grown and developed the talent needed to manage all aspects of its environmental performance, including carbon and aircraft, vehicle and estate emissions. It is this approach that has allowed it to meet the Environmental Noise Directive (2002/49 EU), meeting some of the tightest noise constraints of any airport in the world.

6.4 National and International Engagement

There are a range of local, national and international engagement activities and mechanisms in place which support and challenge its operational excellence. A number of these are highlighted below:

- **Local and Regional**

  Heathrow leads and supports the Heathrow Community Engagement Board and the Heathrow Strategic Planning Group

- **National**

  Heathrow is delivering a series of Business Summits throughout the UK to ensure that UK businesses can maximise their opportunities of any potential expansion.

  Heathrow is also connected with the British Aviation Group, the leading representative body for British companies involved in aviation and airport development and operations.

  Heathrow is a leading member of the Airport Operators Association (AOA), a trade association representing UK airports.

- **International**

  With Heathrow as the UKs only hub airport, it is critical that its air traffic management (ATM) is co-ordinated with other destinations across Europe and the globe. Heathrow is a key partner in the Single European Sky ATM Research (SESAR) project which aims to define, develop and deploy what is needed to increase ATM performance and build Europe's intelligent air transport system.

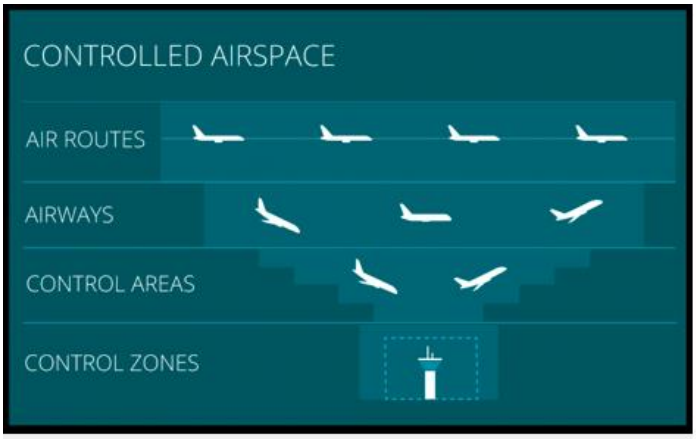
  Heathrow is also an early adopter of initiatives and project outcomes delivered through EUROCONTROL, an intergovernmental organisation addressing ATM challenges across Europe.

6.5 Developments in the wider funding landscape

The research and innovation behind Heathrow Airport's operation provides a strong basis for economic development. The ability for the airport to grow passenger numbers without exceeding its environmental limits has led to a range of world-leading research and technical innovations that are in demand in other airports internationally. The challenge is to enable the expertise base at Heathrow to support the drive for further innovation and commercial exploitation in these world-leading operational areas, balanced with the commitments that come with being a leading partner in the aviation industry.

One of the most significant developments in air transport is the transition of ACDM into Total Airport Management which will ultimately feed into a new UK London Terminal Area (LTMA) fully redesigned digital airspace as part of the CAA overhaul of UK Airspace. Enabled by highly accurate satellite aircraft navigation systems, the digital development has moved to how aircraft are managed through the air routes and down onto the airport.

Working in partnership with the NATS (a unique feature of the UK's aviation industry), Heathrow is leading the developments on the ground to take advantage of the benefits that digital airspace will bring. Advantages include:



Key Airspace Types

- Reduced stacking
- Less slowing down on route
- Less fuel used by aircraft
- Reduced scatter of aircraft on approach
- Increased aircraft movements within a given time window

The modernisation of airports is central to enhancing the passenger experience and providing efficient and sustainable facilities, both key objectives of airport operators in a global economy and competitive environment.[88] The UK Aviation Strategy document (April 2018)[89] states that to be successful in a competitive global environment, it is vital that new technology receives consistent support from identifying demand, through R&D, testing and deployment. As noted in section 3.4, BEIS is investing £1.95bn in aerospace R&D through to 2026, with 50:50 match funding from industry.

7 Intelligent Mobility

All airports have significant mobility requirements and the sector is striving to reduce the carbon emissions from land based transport. Intelligent mobility will have a role to play in reducing the impacts of passenger, cargo or baggage transport. In the last 5 years, nearly 50 consortia have been funded by Innovate UK for autonomous vehicles, and 10% of these have had an airport as a partner, illustrating the role that airports can play as a customer and show-case for these new technologies.

Heathrow Airport is one of the top five busiest airports in the world with a large number of trips made every day as shown in the table.[90]

Average Trip numbers per day (Heathrow)	
Passengers (either starting or ending their journey)	133,000
Workers travelling to and from the airport	88,000
Handling air cargo	9,000
Servicing the airport	1,500
Servicing the aircraft	2,000
Total	**233,500**

It is worth considering that these numbers are only trips to and from the airport and do not reflect internal movements within the airport perimeter itself. These large vehicle movements have an impact on the local road and rail networks which has led to Heathrow developing a range of key initiatives as part of their emerging surface access strategy. As part of their "Enabling more efficient and responsible use of the road network" objective, there is a dedicated sub-objective (G3) dedicated to Intelligent Mobility, which Heathrow defines as:

> *"the use of new technologies and innovative data solutions to improve the efficiency and quality of movement of people and goods. It comprises a package of existing apps and information services and seeks to develop this into a more coordinated offering for travellers".*

By providing leadership on intelligent mobility, Heathrow acts as an anchor business promoting these technologies both within the study area, and also as a global example of best practice. A report by Transparency Market Research[91] valued the Smart Airports Market - Global Industry Analysis at £7M in 2017 and expected it to grow at a compound annual growth rate of 13.0% each year to 2024.

7.1 National and International trends and size of global markets

Within intelligent mobility, there are some key trends that simultaneously will change how transport is operated around Heathrow but also offer large scale opportunities for research and industry within the study area. The key ones are as follows:

Low carbon vehicles - The UK Government[92] has committed to ending the sale of conventional diesel and petrol vehicles by 2040 with the aim that every vehicle on the road is zero emissions at the exhaust pipe by 2050. This aim will require a large-scale switch to

electric, hybrid and alternative fuelled vehicles (like hydrogen). Currently, the infrastructure to support these vehicles is limited and new approaches are required, creating opportunities such as vehicle to grid (V2G). Electric Vehicle sales across all major markets are on the upswing. In 2017, China led the market with just short of 50% market share, followed by Europe with 26%.[93]

Parking technologies - The switch to electric vehicles will also likely speed up the development of smart parking technologies to ensure a dedicated charging point suitable for the vehicle. Enabling technologies for parking include sensors for detecting vehicles, automated bollards that only allow certain vehicles to enter and apps that allow customers to reserve, manage and pay for parking, as well as seeing available spaces. Another trend in parking is the development of automated parking garages, where cars drive into the car park and the driver exits the vehicle. A mechanical system then transports the vehicle to its allocated parking space.

Mobility as a Service - Mobility as a Service (MaaS) is an emerging concept with different interpretations of what it covers. Within the EU, the MaaS alliance[94] has been set up to promote the concept, and they define it as the "integration of various forms of transport services into a single mobility service accessible on demand." A key challenge for MaaS providers is to sign up a range of transport operators and service providers, particularly those who compete. MaaS Services aim to include a wide range of services including public transport, car sharing, bicycle and car hire. A Finnish start-up, MaaS Global have done the most to promote the concept of MaaS and their "Whim" app is live in Helsinki, Finland and in Birmingham. Whim provides a transport allowance model where you pay a differing level of subscription to get a differing level of transport access.[95]

Connected and autonomous vehicles - The technologies involved in Connected and autonomous vehicles can be applied to any type of vehicle including passenger cars, freight, service vehicles and public transport. Typically, Connected and Autonomous Vehicles combine two key concepts. The first is that of connectivity, the ability for vehicles to communicate with each other, the second is autonomy, so that a vehicle can travel without a driver active for all or part of the journey. The move to fully autonomous vehicles will be a gradual one, where the technology capabilities grow and allow vehicles to be more and more autonomous. Within the industry, the race is on to develop the first fully autonomous vehicle. Predictions vary about when this could be commercially available, and commentators state anything between 2022 and 2030.

7.2 Local Science and Innovation Assets

The study area is well located to leverage the innovation and strengths within Greater London. A number of key government bodies are involved in Intelligent Mobility, including:

- **Centre for Connected and Autonomous Vehicles (CCAV),** which is a leading governmental organisation whose role is devoted to promoting and provding leadership and funding for Connected and Autonomous Vehicles in the UK
- **Future Cities Catapult:** who support and promote innovation for urban areas in the UK. They are focussed on integrated urban infrastructure, healthy cities and urban mobility.

Within the study area, there are significant innovation and research organisations working on developing Intelligent Mobility, including the Transport Systems Catapult, Transport Research Laboratory and the universities mentioned in earlier chapters.

In addition, **Mclaren Applied technologies**, based at Woking, is a technology and design centre focused on motorsport, automotive, public transport and health. They specialise in sensor technology, telemetry, electronic systems, software, simulation, predictive analytics and design. As part of the wider McLaren group, they can leverage cutting edge technologies developed for the F1 team.

Brompton e-bike (Perivale, Ealing)[96] manufactures the Brompton Electric bicycle that provides assistance when you need it, flying up hills or on a long journey for example. Brompton provides intelligent mobility manufacturing in the study area, and have decades of experience in innovative urban journeys.

7.3 Local Science and Innovation Talent

As illustrated in previous sections, Intelligent Mobility is about much more than vehicles, it is about the technology and data solutions centred around the user. Our study area has the science and innovation talent, and the industry pull to make Intelligent Mobility a specialism. Innovate UK and CCAV funded pilot and demonstration projects are harvesting and developing local science and innovation talent, and creating ambition to establish a West London Cluster.

Heathrow has run driverless trials and is an active partner in the Capri, Synergy, Insight and Gateway projects. These projects seek to build upon the successful electric automated pod scheme which links Terminal 5 to parking and hotels. Currently, these pods are restricted to travelling on segregated tracks. The funded projects seek to develop the pod system into a fully autonomous vehicle that can provide last mile transportation, each considering a different part of the pod service.

The recently completed Gateway project, which was led by TRL, held public trials along the Greenwich peninsula, by the river Thames. Market research conducted by the project indicated broad support (78%) for the idea of driverless vehicles on urban streets, provided they are safe and resistant to cyber-attack.[97]

Building upon the Gateway project, TRL has been awarded £19.2M by the UK Government to develop a Smart Mobility Living Laboratory in London. The project is an open innovation environment designed to develop technical and business solutions involving smart mobility. It provides a real-world urban test bed and complex public environments. It allows the performance and benefits of CAV technology and mobility services to be assessed. The fact that this project is led by TRL and is close to our study area will provide good opportunities to attract and develop talent and further innovation or funding.

Science and Innovation talent linked to the wider transport infrastructure will also be important. Heathrow is adjacent to the M4 and M25 motorways. Smart motorways will be

an enabler and test bed for intelligent mobility. The Heathrow Connect service, Crossrail and the longer-term plans for western and southern rail links to the airport will also attract talent and skills for MaaS and other innovation passenger services.

7.4 National and International Engagement

The Centre for Connected and Autonomous Vehicles (CCAV) coordinates UK wide activities in this area creating a funding environment for collaboration which develops and trials CAV technologies in the UK. Conigital connects across the whole UK market by coordinating the Midlands Connected Autonomous Vehicles (MCAV) cluster. Conigital have already catalysed an embryonic West London CAV cluster, and are engaged with a range of Horizon 2020 projects which will enable an International CAV Cluster in the near future subject to funding.

There is large demand internationally for new vehicle types: Westfield recently signed a Memorandum of Understanding with the Emirate of Dubai around the provision of large scale pod systems. They have also attracted significant interest from countries around the world including South Korea and the USA.

7.5 Developments in the wider funding landscape

The market for CAVs in the UK (specifically, for road vehicles with CAV technologies) is estimated to be worth £28bn in 2035, capturing 3% of the £907bn global market[98]. There would be an estimated 6,000 direct UK jobs in the production of CAV technologies, with a further 3,900 indirect jobs created in the supply chain for these technologies. 70% of these jobs are estimated to be in software related industries, where our capabilities are strong.

The aviation industry is usually the bearer of the cost of enhancing the transport system for the benefit of its customers. However in the case of intelligent mobility developments, the UK is well placed to be a leader in this technology, and the government wants to seize that opportunity.[99]

8 Conclusions

The hypothesis that this Science and Innovation Audit set out to explore is that:

Science and innovation excellence supporting 'Sustainable Airports' within our study area, can be boosted to drive further innovation in the UK, and to enable global exploitation.

Heathrow's location within the study area provides a unique technological challenge for research organisations and innovative suppliers; to maintain very high efficiencies and levels of customer service within fixed resource and environmental envelopes. Using Heathrow and its supply chain companies as a sustainable innovation testbed, with demonstration and innovation projects to pilot and validate new ideas and accelerate innovation, is an excellent way to showcase new technologies to the world. The research organisations in the study area are evidently well connected to national and global innovation networks and developing scientific knowledge of importance to sustainable airports, across all four of our technology themes. Thus there is a clear and timely opportunity to progress sustainability through innovative inter-disciplinary research programmes strongly aligned with future airport development challenges and where commercial or social value can be generated.

8.1 Gaps and Barriers to Innovation

The audit process allowed the identification of gaps in the study area's skills and innovation landscape. Some of these emerged through the interaction with industry or innovation agents, others are apparent from the data analysis. The key gaps identified are:

- The connection between the research base and industry supporting innovation in sustainable airports exists but could be stronger and more diverse
- The economic competitiveness of our study area means that physical/commercial space for businesses to grow is at a premium
- There are no incubators or accelerators specific to our themes, and relating directly to sustainable airports, within our study area
- There are significant higher-level skills shortages to grow innovation in particular themes, e.g. Cyber Security for Aviation.

There are barriers to innovation at airports, inherent to the operation of the airport, such as the regulatory environment and associated investment timelines, high safety standards and the difficulty of trialling new products and services safely without affecting the efficiency of the airport.

These barriers can be overcome to some extent through the facilitation of co-innovation across the whole supply chain, as well as infrastructures such as innovation centres

embedded in the airport estate or digital twins to experiment with innovation away from the airport.

8.2 Recommendations and Next Steps

The audit recognises the critical importance of this sector to the UK economy, but also that historically the sector has not engaged strongly with the research base. As highlighted in the Industrial Strategy, the UK's frontier businesses (most productive) have strong connections with the research base, with an unusually long tail of underperforming businesses pulling the average UK productivity down.[100] Thus the main recommendation of this audit is that more needs to be done to ensure that the research excellence in the region is harnessed to ensure that more innovative technologies for future airports are developed and translated into increased exports, increased productivity and economic growth.

To address the disconnect between the airports sector, its supply chain and the research base, an Innovation Centre/Research Centre/ Catapult-like centre should be established. The Centre could work with all stakeholders to co-create research programmes to address future airport sustainability challenges. If situated on or close to the airport, it could use the airport as an innovation test bed, helping to ensure the airport and its supply chain partners establish the UK aviation industry as leaders in global sustainability. The Centre could incorporate:

- An Airport Habitat Lab as described in section 5.2.
- A West London 'Intelligent Mobility and CAV Cluster'. This will help to grow the network within our study area. Brunel University London and Conigital are also keen to explore setting up an 'Airports CAV Accelerator' as a next step.
- A new route to market by which innovative products and services, including those from start-ups, to support sustainable airports could get rapid visibility, evaluation and potentially then promotion to buyers.
- A market leading simulation facility to expedite test and development of airport operation innovations.

The Centre would also act as an accelerator, bringing solutions to the airport community more quickly through collaboration, mentoring and services. Funded through a basket of leveraged funding from Research England, the Industrial Strategy Challenge Fund, and the Strength in Places Fund, it would foster close collaboration between airports, government agencies, strategic partners, industry and investors.

The Centre could take forward the idea of a Heathrow 'Kite Mark' which when applied to products and services make them very 'exportable'.

The development of collaborative innovation facilities at the natural meeting point of the three different economic geographies existing in Thames Valley & Berkshire, Buckinghamshire & Hertfordshire and West London will support wider regional collaboration, enhancing the relative strengths of the three areas and supporting research innovation to further increase productivity and growth. The success of the Centre would strengthen the case for an Enterprise Zone for Sustainable Airports, providing opportunities

for SMEs developing the innovation technologies emerging from the Centre to expand whilst remaining in the region.

Our more detailed recommendations are divided into 5 sets, one overview and then a further set for each of our themes.

8.2.1 Sustainable Airports Overview Recommendations:

1. The consortium plans a series of opportunities to increase interaction across the innovation ecosystems established by this SIA, including the Innovation Centre described above.
2. The consortium establishes a follow on working group (with expanded partners) to develop a stronger characterisation of the research needs of the sustainable airport sector.
3. The consortium works to establish sustainable airports as a priority for UKRI's Strategic Priority Fund, supporting high quality strategic R&D opportunities that might otherwise be missed.
4. The consortium supports and develops the provision of higher apprenticeships and graduates in areas of skills shortage such as big data, cyber and construction as well as the upskilling of employees whose roles are increasingly replaced by digital technologies. This would include establishing
    a. a doctoral training centre to produce a cohort of researchers, able to work in universities or industry, attuned to the research challenges of sustainable airports.
    b. A higher apprenticeship in Digital Airports.
    c. Development of AR/VR and other innovative tools that advance the re-skilling of staff into higher value roles
5. The Consortium engages with the Department for International Trade to promote export opportunities for UK firms developing technologies for sustainable airports. This will be guided by both this report but also strategies such as the Cyber Security Export Strategy.[47]

8.2.2 Sustainable Construction Recommendations:

1. Consortium partners establish a formal Research Cluster on Sustainable Construction for Airports, which feeds into and benefits from the i3P platform and network, and is focussed on the particular needs of the region.
2. As well as supporting innovations in future pavement, airside and terminal construction, the Cluster will look to support the Heathrow Logistic Hub initiative as a strategic intervention in the drive to modernise UK construction, making it a manufacturing sector, enabled by smart technologies. The Cluster should encourage disruptive innovations in the provision of higher-density industrial space in the region, as well as complementing and feeding into the Core Innovation Hub for construction which is being established.

8.2.3 Big Data and Cyber Security Recommendations:

1. The consortium uses its networks, and the case studies illustrated in this SIA, to continue development of common standards for data across airport systems and the airport sector to encourage, and enable, further research and innovation.
2. Working with its networks and partners, the consortium develop tools to help compliance to emerging APOC standards. Such tools would have clear export opportunities.
3. The UK's Cyber Security Export Strategy, published in March 2018 will help UK cyber security companies to showcase their capability as well as to find and secure opportunities to export. Cyber Security for Sustainable Airports should be a key piece in this offer.
4. The consortium finds opportunities to develop open models for data analytics, that are trusted or validated by a body or community. Such an initiative would be particularly beneficial to airports, where multiple data sets could be combined to improve passenger experience, efficiency, security and create new markets.

8.2.4 Operational Excellence Recommendations:

1. The universities in the study area support the airport sector in developing numerical and simulation tools for a more efficient use of the airspace, support adaptation to, and management of, disruptive weather events, ahead of the digital transformation of airspace, and to make use of the airspace in a way that reduces the environmental impact.
2. The consortium work with the airport to identify opportunities to introduce waste valorisation technologies, innovative technologies that reduce the resource consumed by waste management and efficiencies driven by the introduction of innovative building information modelling.
3. Given the importance of logistics and transport to the region, we recommend the research and innovation partners come together to develop best practice in the development of smart, sustainable, scalable supply chains. This would bring together cutting edge technologies from big data, cyber and operation excellence to create tomorrow's supply chains for smart circular economies.

8.2.5 Intelligent Mobility Recommendations:

1. Consortium partners to support and champion the West London 'Intelligent Mobility and CAV Cluster' which is now being established, as well as exploring the potential for growth in CAV test sites within the study area.
2. The consortium support the use of Heathrow as a demonstrator for multi-modal mobility as a service.
3. Work with Heathrow to identify applications for autonomous airside technologies, which longer term could lead to substantial reductions in energy on the taxiways by removing the need for lighting.

Reflection

INNOVATION FOR SUSTAINABLE AIRPORTS AND REGIONAL COMPETITIVENESS

The ability of business organisations, regions and nations to create and capture wealth in international markets over time (sustainable competitiveness), depends on a plethora of interacting economic, geographical, institutional, political, cultural and other factors. Decades of research, learning and doing have led to the conclusion that *entrepreneurial and organisational (private and public) infrastructure, strategy and policies, innovativeness, resources and capabilities, and learning,* are critical sources of wealth creation and capture through the development and commercialisation of tradable products and services. These are fostered by 'critical mass' of activity that helps reduce unit costs of production, engendering offerings of comparative or better quality, at a lower cost than competitors. These are easier to develop in places, regions and economies that are diverse and diversified from the basis of a 'stronghold'-an area and/or activity of excellence, (smart) specialisation and 'scale'. Scale economies are achieved *by large organisations and/or by interconnected business ecosystems, knowledge and business networks and clusters.* Large organisations like Heathrow Airport can often help co-create the business ecosystem serving as 'anchor tenants'.

In its latest phase, globalisation involves the slicing of value chains (GVCs) in increasingly finer activities by multinational enterprises (MNEs), which orchestrate and largely control the process. Trade of final products and services is superseded by trade in highly specialised activities in GVCs, sometimes comprising a single specialised part of a final product. Competitiveness is best fostered when these qualify as a non-imitable ('bottleneck') assets. For example, Rolls-Royce produces parts for airline engines hard to replicate because of the tacit knowledge involved in their production. Location itself can serve as a bottleneck asset.

Under globalisation location and place-based strategies become critical in supporting, complementing and sometimes counter-balancing non-compatible or supporting business strategies by MNEs. Besides creating wealth locally, clusters and business ecosystems help attract inward investment by foreign companies. Their knowledge base helps 'absorb' new knowledge, hence embed foreign investments into the local economy. Cities, regions and locally-based business ecosystems can be connected to, complement, underpin and challenge MNE-controlled GVCs. This fosters resilience and sustainability. Many a catching-up and developed economy employ business ecosystems and/or clusters as a way of upgrading their economies.

Activities involving tacit, non-codifiable knowledge, embedded in locations, history and legacy, and system architectures, with high income elasticities of demand (that become more highly demanded as incomes increase), require a vibrant manufacturing base, and/or benefit from a combination of manufacturing and services. Additionally, small and medium firm creation and growth requires a level playing field. For markets to work, competition is a key ingredient, as is collaboration and cooperation. These call for developmental place-based industrial strategy (IS) and regulatory policies-the UK government's current IS being a case in point.

Like everyone else, the public sector has bounded knowledge, limited resources and capabilities, while the private sector often lacks the scale or incentives to develop critical skills and competencies-in this context incentive aligned public-private collaboration is often critical. The co-diagnosis and upgrading of business ecosystems and clusters is a key means through which the limited resources and attention spans, can be leveraged in a focussed manner to optimise impact. A single company or organisation with requisite support and advice can often help co-create a business ecosystem, especially when it is locally based. Heathrow is ideally posited to play this role.

This report demonstrates that West of London and Heathrow have the potential to serve as a regional leader and help co-develop a regional ecosystem of excellence that supports the UK industrial strategy and national competitiveness, building on strength. The consortium's skills and competences can help realise this vision, by supporting and implementing a place-based regional competitiveness strategy built around a sustainable Heathrow Airport -based resilient West of London ecosystem.

Professor Chris Pitelis

Brunel University London, and Fellow of Queens' College, University of Cambridge.

Professor Pitelis has extensive research, publication, consulting and practical knowledge in devising and implementing developmental regional and national place-based industrial and competitiveness strategies and the diagnosis and upgrading of regional business ecosystems and clusters in numerous countries.

Appendix 1: Members of the SIA Advisory Board

Ian Barham	Buckinghamshire Thames Valley LEP
Geoff Brighty	ICE blue
Ross Burton	SMART Specialisation Hub
Andrew Dakers	West London Business
Don Dhaliwal	Conigital & MCAV
Viola Hay	SMART Specialisation Hub
Bill Hicks	Thames Valley Berkshire LEP
Professor Paul Hogg	Royal Holloway University London
Neil Impiazzi	SEGRO
Andrew Kershaw	Brunel University London
Alison Nicholl	BRE
Olu Odeniyi	Former Chairman & CEO Maidenhead and District Chamber of Commerce
Ian Parkinson	Morgan Sindall
Ant Parsons	ICE blue
Matt Prescott	Heathrow Airport Ltd.
Deborah Pullen	BRE
Professor Geoff Rodgers (Leader of the SIA)	Brunel University London
Rosa Scoble	Brunel University London
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