Institution: The University of Leeds

Unit of Assessment: B14 Civil and Construction Engineering

a. Overview

The University of Leeds's submission to the Civil and Construction Engineering Unit of Assessment (UoA) encompasses two academic schools, the School of Civil Engineering (SCE) in the Faculty of Engineering and the Institute for Transport Studies (ITS) in the Faculty of Environment. The schools have common roots, retain significant links with three joint posts and have increasing synergy in their research strategy and activity. This joint submission reflects two key characteristics, which are our ethos of working at the interfaces with other disciplines and our working on key societal and technical challenges associated with infrastructure. These characteristics allow us to develop innovative research that addresses societal needs in the face of rapid changes whether environmental, economic or demographic. This has brought research success in established areas and led the way in emerging areas that are high on the agenda of business, government and research funders.

Each of the two schools is responsible for staff and financial management whilst research is focused across three institutes: Pathogen Control Engineering (PaCE), Resilient Infrastructure (iRI) and Transport Studies (ITS). PaCE takes a global outlook, investigating the interactions between infrastructure, the environment and human health. Key areas include resource recovery from wastes, bioremediation, airborne disease transmission, water and sanitation. iRI is concerned with ensuring that the physical infrastructure systems underpinning our way of life can adapt to changes, both in the way we use them and in the social and physical environment in which they are created, designed, built and operated. ITS undertakes richly multi-disciplinary, transport-related research at the interface between academia, policy and practice.

Highlights in the UoA in this REF period include:

- ITS's award of a 2009 Queen's Anniversary Prize for Higher and Further Education in recognition of *'sustained excellence: 40 years impact in transport research and teaching'*.
- SCE's active research-led recruitment and promotion strategy has aligned the staff and research portfolio towards emerging interdisciplinary research agendas, enabling a sustainable upward trajectory for funding and output quality.
- Research on railway economics has had major impact on government policy and official practitioner guidance; for example, the strategic case for HS2.

Below we expand on these highlights with more detail and evidence.

b. Research strategy

Research across the UoA is based around a vision of inter-disciplinarity, which combines specialist expertise with a sophisticated and radical interpretation of the social, economic and political context in which it is exercised. This outlook is essential to address key global challenges in the face of rapid changes in the built environment.

SCE review since RAE 2008

In RAE 2008 SCE had two stated strategic aims for the following period: "i) greater multi-disciplinary research by establishing teams across academia and industry and ii) sustainability as an inherent and integral theme across our research".

After RAE 2008, SCE carried out a fundamental review of its research strengths and how these mapped onto emerging engineering research areas and future societal challenges. This led to the creation of two research institutes aligned to the above aims with the remit to strengthen the culture and leadership of research in the School. The two institutes are the Pathogen Control Engineering Institute (PaCE) under the leadership of *Noakes* and the Institute for Resilient Infrastructure (iRI) under the leadership of *Purnell*. As well as providing a clearer focus for existing research in fundamental areas, the institutes provide a demand-led structure for the underlying civil engineering activity, enhancing their ability to operate across discipline boundaries. Both institute heads are part of the School's Strategy Group.

Evidence of achieving the first of the above aims, i) **greater multi-disciplinary research**, is (with reference to outputs in REF2 in brackets):

- A new line of research on bioremediation has led to significant scientific discoveries on the use of biosensors and microbially-mediated reduction of contaminants in soil and groundwater (*Stewart 3, 4*). This has been established through collaboration internally and externally across engineering, environmental science and biological sciences along with industry.
- Our pioneering research on sustainable and resilient infrastructure has led to funding from RCUK sandpits, calls and discipline-hopping awards (EP/I030735/1, EP/J00555X/1, EP/J005576/1, EP/K012398/1, EP/K012770/1, EP/K013661/1, NE/K015834/1). This has combined engineering, economics and social science to investigate criticality of materials in infrastructure and radical utility supply and also brought together novel methods of predicting flooding with the behaviour of individuals and the wider economic impacts. This has led to collaboration with several research groups and clusters across the University of Leeds including the *Sustainability Research Institute*, *ITS*, *water@leeds* and *Leeds University Business School* along with collaboration with UC Irvine (*Wright 4*) and the Chinese Academy of Sciences.
- Research on indoor air quality has given new insights into transmission of airborne infection and control through UV-C light and ventilation (*Noakes 1-4; Sleigh 1, 3*). This has brought a substantial growth in funding (EP/G061327/1, EP/G008663/1, EP/K021834/1, EP/G029768/1) and collaborative research with academic and industry partners across engineering, architecture, mathematics, microbiology and clinical practices.

Achievement of the second aim, ii) **sustainability**, is evidenced through the above and:

- Innovative work on energy and resource recovery builds on our long track record in the treatment of wastewater and solid waste and has led to key scientific achievements including novel processes for anaerobic digestion of sewage screenings, nutrient recovery from process waters released via microalgal uptake and solid waste management systems (*Horan 4*; *Camargo-Valero 1, 2*; *Velis 1*).
- Our work on Quantitative Microbial Risk Analysis (QMRA): the first comprehensive analysis of the risk of infection from the use of wastewater in irrigation (*Sleigh 2; Case Study 5*) has led to this being adopted internationally.
- Proof of their viability low-carbon construction materials from waste has been demonstrated in key papers (*Forth 3*) and has led to a spin-out company, ENCOS.
- Research on embodied carbon in the built environment has moved beyond analysis of each material to focus on the functional unit, thereby challenging conventional thinking (*Purnell 1, 2*).

ITS review since RAE 2008

Since RAE 2008, ITS has made significant changes to its staffing, due in part to the retirement of a cohort of senior staff. The opportunity was taken to carry out a fundamental review of research organisation and leadership which led to a new senior leadership team led by *Marsden, Batley, Jamson* and *Whiteing* and development of the leadership role of Research Group Leader (RGL). RGLs (currently *Smith (A), Shepherd, Hodgson, Merat*) are now members of the School Management Team, have responsibility for the development of research and innovation strategies at the research group level, and are allocated strategic funds to support the implementation of those strategies. These changes to the RGL role were commended in the context of ITS's 2013 Investors In People (IIP) assessment.

In RAE 2008, ITS's over-arching strategic aim for the subsequent period was "Internationally excellent research with an unrivalled impact on policy through publications, influential governmental work, international exchange and engagement, and inter-disciplinary mix".

Each of our research groups has built on its reputation for **internationally excellent research**. Highlights are:

- Fundamental research on estimation and inference in discrete choice models (*Daly 1*; *Hess 1*) has been complemented by novel applications (*Batley 2*; *Wardman 2*), authoritative meta-analysis (*Wardman 1*), and the linking of discrete choice and market-level demand models (*Batley 1*).
- Excellence in network modelling has attracted new collaborations with leading international

researchers (e.g. *Watling 1, 2*; *Connors 4*), whilst the established reputation in traffic flow theory (e.g. *Carey 1*) has been combined with emerging talent (e.g. *Ngoduy's* EPSRC Career Acceleration Fellowship, EP/J002186/1).
- In response to the changing priorities of transport policy, agenda-defining research has been developed in areas such as governance (*Marsden 3*), network resilience and disruption (*Marsden 4*), social exclusion (*Lucas 1, 2, 3*), and household energy demand (*Wadud 1, 2*).
- Internationally-leading expertise at the human-to-vehicle interface has been maintained and further developed, through research on highly-automated driving (*Carsten 3; Merat 4*), in-vehicle distractions (*Carsten 2*) and Intelligent Speed Adaptation (*Carsten 4; Jamson 1, 2; Case Study 3*), and the 5-year £1.28M Programme for Simulation Innovation (PSI) award from EPSRC and Jaguar Land-Rover (RG.TRAN.481590) has reinforced the world-class status of the University of Leeds Advanced Driving Simulator.

The Institute has established new areas of research which cut across disciplines, reflecting our commitment to tackling global challenges with new **interdisciplinary** partnerships. For example:

- In the area of transport and energy, ITS is a major player in a new End User Energy Demand reduction centre (*Marsden*, RG.TRAN.484458).
- Similarly we have developed our transport and health portfolio through work with the London School of Hygiene and Tropical Medicine on the health impacts of free bus travel. (*Kelly*, RG.TRAN.480280).
- The €10M EcoDriver project brings together members of three ITS research groups to understand the impacts and benefits of new technology on emissions. (*Jamson*, RG.TRAN.481661).

ITS's research has had broad and significant **impacts** on safety, economy and public policy and services. For example:

- Important research has been carried out on the effectiveness of speed cameras (*Maher 1*).
- Valuations of travel time savings and forecasts of the demand response to travel time savings have formed a key input to the economic case for High Speed 2 (*Case Study 1*).
- Path-breaking research has exposed the inadequacy of NO_X emission controls on diesel vehicles and shaped European legislation on low emission zones (*Tate 1, 2*).
- Econometric modelling of rail costs and efficiency has stimulated substantial improvements in the efficiency of Network Rail (*Smith (A) 2; Wheat 3*; *Case Study 3*).

Cross-campus and outreach

In line with our vision, all three institutes collaborate across the Leeds campus and each has engaged significantly with the University's strategic initiatives. A major focus is *water@leeds* which brings together over 150 researchers across several faculties and has built on an initial investment in four academic posts by generating over £16.5M of funding since 2009. SCE houses the Industrial Research Director of *water@leeds* and through *water@leeds* has won a number of externally funded projects (EP/K012770/1, EP/K013661/1, EU BASE, NE/K015834/1). ITS is home to a HEIF-funded *Transport Systems Innovation Hub* (*Carsten, Merat*), and also has substantive links to the University's *Centre for Integrated Energy Research* (e.g. through *Wadud's* shared post). SCE has been actively involved in two further significant cross-campus initiatives. Firstly, SuRe-Infrastructure brings together iRI, the Sustainability Research Institute, and Leeds University Business School and has secured over £2M in new funding from RCUK. Secondly, the Energy Technology Innovation Initiative (ETII) with the School of Process, Environmental and Materials Engineering has facilitated research on building environment and performance and EC funded research to develop a novel low carbon energy extraction by combining the underground coal gasification (UCG) with CO_2 capture and storage (CCS).

Research within the UoA also interacts with a wide range of key end-users including government, regulators, utility and infrastructure providers, contractors and consultants (details in Section (e)). Yorkshire Water, Indah Water Konsortium and Arup have signed Strategic Partnership Agreements with the University of Leeds during the REF period based upon long standing research collaborations with various schools including SCE and ITS.

Research Strategy across the Unit of Assessment, 2014–2020

Given our common focus on interdisciplinary approaches and methodologies to societal challenges, SCE and ITS plan to further integrate research. This leads to the following overall strategic goals:

G1. Develop a new and ambitious transdisciplinary agenda that addresses societal grand challenges by applying cutting-edge engineering and scientific expertise.
G2. Publish high quality research that has internationally leading impact in academia, stimulates debate, and changes policy and practice.
G3. Ensure that high quality, innovative research makes a real impact outside academia (see REF3a).
G4. Recruit and retain staff who will conduct internationally-leading research within an interdisciplinary context and obtain funding to support this.
G5. Maintain a diverse range of funding sources to ensure the sustainability of our research.

Across the UoA, our work on experimental investigations, modelling, design and behavioural response will focus on the interaction of engineering and science to ensure the resilience of our infrastructure systems, deliver resource and energy efficiency, and enhance the health and well-being of societal stakeholders. Integrated research on these topics will be pursued across the UoA through existing and newly-appointed joint ITS-SCE staff (*Smith (N), Choudhury* and *Wang*), supported by regular meetings of Heads of School and Directors of Research and Innovation, active investment in the co-development of research strategy and grant planning. Interaction and cohesion of researchers across the two schools will be further enhanced by continuing our regular research days and postgraduate conferences to stimulate new collaborative ideas. Complementing this, SCE and ITS will pursue the more detailed strategies below.

Strategy: SCE

Whilst remaining responsive to emerging demands, over the next period SCE will develop research to address the following societal challenges across both of its research institutes:

S1. Our critical mass of funding (>£2M) has established Leeds as a key player in **Sustainable and Resilient Infrastructure** and in the next REF period we will transform the way infrastructure is managed through analysis of the complex interplay between value, resilience, technical performance and durability.
S2. Research across PaCE and iRI on **Building Environment and Performance**: we will develop innovation in building ventilation, materials, energy performance and human factors to allow us to provide innovative solutions for industry. This will be done in collaboration with the Energy Technology Innovation Institute (ETII) at Leeds.
S3. **Environment and Health**: we will build on success in understanding airborne infection to better quantify risks and develop optimum engineering solutions. We will further develop integrated approaches to water and sanitation challenges in the developing world including building on policy impacts (*Case Study 5*) and strengthening collaborations at Leeds.
S4. **Resource recovery**: building on established strengths in anaerobic digestion and developing emerging areas of algal bioenergy, recovery of nutrients, coal degasification/CCS and resource recovery from municipal solid waste. Research will involve further collaboration with ETII, including the development of shared laboratory facilities planned for 2013/14.
S5. Continued leadership in *water@leeds* to develop multi-disciplinary approaches to the increasing challenges **water management** including flood risk, water footprinting, water sensitive urban design and reducing energy use in the water industry.

Strategy: ITS

Beyond REF 2014, the Institute is well-positioned to continue developing and exploiting the cross-disciplinary agenda outlined above. Specific action areas will include:

S6. **Energy demands of future mobility**: this theme will synthesise research interests in fuel demand, energy end use, eco-driving, and green logistics, to establish ITS as a leading international player on the theme of transport and energy.
S7. **The role of transport in resilient socio-technical systems**: this theme will draw together the mutual interests of ITS and iRI in ICT, governance, network disruption, behaviour

change, social exclusion and the valuation and modelling of reliability and punctuality.

S8. **Modelling complex multi-scale networks**: we will synthesise strands of existing internationally-leading expertise in the modelling of networks, individual choice, market and firm behaviour, system dynamics and micro-simulation, in order to develop models of socio-technical infrastructures from the local to the global scale.

S9. **Open data, sensors, mobile communications and managing the transport system in real-time**: existing strengths in data collection, monitoring, and micro-simulation will be harnessed in developing ITS's position within the digital economy research agenda.

S10. **Railway research**: building upon ITS's international reputation in the economic modelling of the railways, and linking with cognate interests such as governance and human factors, we will develop a centre of excellence in railway policy, planning and analysis.

S11. **Informing the design of intelligent vehicles**: combining existing expertise in human factors with emerging interests in the socio-technical interface, we will develop research on the human-to-vehicle interaction.

S12. **Estimating the costs and valuing the benefits of policy and infrastructure:** established ITS economics expertise will be applied to new problems in health, engineering and the utilities, supporting SCE's interest in the development of innovative business models.

A number of these cut across the UoA and will be jointly developed: S1 & S13; S2 & S7; S3 & S13. In this way work across the UoA will develop joint goals of addressing societal challenges through a truly inter-disciplinary approach.

c. People, including:

i. Staffing strategy and staff development

Achieving our research strategy requires a supportive and inspiring environment across the UoA along with intellectual leadership for excellence in research. Recruitment and retention of staff through the strategy set out below are seen as key to this. Both schools operate a research-led appointment process to recruit staff who can actively contribute to the strategy outlined above thereby ensuring synergy between our collective goals and individual career advancement. As well as high-level expertise in their specialist area, appointees must have a vision for how this expertise fits into our multi-disciplinary research on key societal challenges.

In 2012-3 SCE and ITS have made two joint appointments (*Choudhury*: Transport Engineering in Emerging Economies; *Wang*: Resilient Transportation Systems) to further develop joint research. These two are working along with the existing appointment of *Smith (N)* to develop specific research whilst also facilitating collaborative research between other colleagues.

Since RAE 2008, both SCE and ITS have implemented significant changes to personnel. Retirements have allowed for strategic appointments that support the UoA's research, through increased activity and progression in research culture and quality. The outputs submitted in REF2 draw significantly on newly appointed staff including six Early Career Researchers (ECRs).

Across the UoA we have strengthened our ability to deliver our research strategy through:

- New appointments to deliver specific strategic objectives (references in brackets refer to the objectives detailed in Section (b) above):
  - iRI: *Hughes* (S2; Lecturer, from Heriot Watt; now Associate Professor), *Nikitas* (S1; Lecturer, from Bristol), *Purnell* (S1; Reader, from Warwick; now Professor), *Tsavdaridis* (S1; Lecturer, from City).
  - PaCE: *Tillotson* (S5; Director of *water@leeds*, from Yorkshire Water), *Velis* (S4; Lecturer, from Imperial), *Wright* (S5; Professor, from Delft).
  - ITS: *Lucas* (S7; Senior Lecturer, from Oxford).
- Staff have been successful in promotion: *Black, Hughes, Liu, Merat* and *Sheng* to Associate Professor; *Noakes* (holder of an EPSRC Challenging Engineering Award in Hospital Ventilation) and *Stewart* to Reader; *Hess, Marsden, Purnell, Richardson* and *Shepherd* to Professor. Identification of academic leadership potential among research staff has led to promotion (*Camargo-Valero* (S4) and *Yang* (S2)) to permanent academic posts (ECRs).
- The following have been appointed to fellowships with the objective of developing new academic careers: *Berreta* (S5, *water@leeds* appointment), *Ferreira* (S7), *Hibberd* (S11),

Roelich (S1, joint with the Sustainability Research Institute), *Thornton* (S3), *Shirley* (S2), *Tanner* (S6, S12) and *Khan* (S3).

- In addition to the new ITS-SCE shared posts, we have supported our strategy by appointing to further shared posts in energy (*Wadud*; S6) and health (*Kelly*; S3, S12), and renewing established shared posts with Leeds University Business School (*Smith (A), Toner*; S10, S12).
- Along with the Energy Technology Innovation Initiative (S2), we have recruited *Heyes* (Professor from Imperial College), *Jaworski* (Professor from Leicester) and *Mao* (Lecturer from Leicester) for our Centre on Energy in the Built Environment; in REF 2014 these are being entered in another Unit of Assessment.

Staff Development across the Unit of Assessment

Recruitment: our new recruits are diverse, supporting internationalisation of research and bringing new perspectives and approaches. To ensure high quality research and vision we dedicate significant time to recruitment. Staff are active in identifying suitable applicants and are involved in the appointment process which includes candidate presentations to all staff, teaching and research discussions with key staff and formal interviews. Rather than recruiting staff to tightly defined research topics we seek to recruit staff who have the vision to identify future trends in their field and actively exploit these through a broad perspective. This allows them to contextualise their technical knowledge to address societal challenges and to lead inter-disciplinary teams.

Probation, mentoring and progression: the UoA has established mechanisms to support new and existing staff whilst also monitoring performance in order to make clear how staff can contribute to the school's research strategy. New staff, particularly ECRs, are supported through investment in equipment (see Section (d)), provision of travel funds to develop collaborations, funding for PhD studentships to assist in establishing an independent research career and reduced duties for teaching and administration. New staff are assigned a more senior colleague as a probationary mentor, ensuring identification of key work objectives and training needs, and encouraging early momentum in their academic careers. Further mentoring takes place through institute and research & innovation directors and/or from appropriate staff across the University.

Annual Staff Review and Development (SRDS) meetings are used to identify an individual's goals and training needs and to support staff in gaining promotion. An Annual Academic Review is also conducted in which each member of academic staff meets with the Head of School and the Directors of Research & Innovation and Student Experience in order to consider the workload across research and teaching. This also provides an overview of activity, advises on priorities and identifies where the school can assist in further enhancing outcomes. This allows us to develop realistic objectives in each area and to align the individual's career aspirations with school strategy.

ECRs are also supported through the University training programmes for newly appointed academics which covers both teaching and research. Staff in the UoA make extensive use of internal training courses and key staff are encouraged to undertake training for research leadership through the "Tomorrow's Leaders" programme.

The University's Employment Policy for Research Staff describes how the University addresses Concordat to Support the Career Development of Researchers. The policy provides a statement of the University's expectations for the support, management and development of researchers. It covers key aspects of employment and the responsibilities for implementing and delivering the policy in faculties, schools and across the University. In December 2010, Leeds was awarded the HR Excellence in Research Award by the European Commission in recognition of our commitment to ensuring good working conditions and career development for researchers.

During the assessment period, *Hess* (ECF/2008/0103) and *Ngoduy* (EP/J002186/1) were awarded fellowships by Leverhulme and EPSRC respectively, and *Noakes* was awarded an EPSRC Challenging Engineering award (EP/G029768/1); the latter is a substantial award (£1M, 2009-2014) in the area of healthcare ventilation, which supports three PDRAs and three PhD students. Both schools have also invested school funds in fellowships occupied by *Shepherd, Ibanez, Ngoduy, Shirley* and *Khan* with a further fellowship funded by *water@leeds* occupied by Berretta. In the case of *Ngoduy*, this acted as a platform for his subsequent EPSRC fellowship success.

Equality and Diversity: equality issues are considered central to maximising the potential of our

staff to deliver world class, innovative research and to ensuring a supportive and professional working environment. The University's Equality Service leads good practice throughout the University across the main protected characteristics (race, sex, gender reassignment, sexual orientation, religion or belief, disability, pregnancy and maternity, marriage and civil partnership, and age). The University was awarded Athena Swan Bronze in 2008 and has renewed this award in 2013. The Faculty of Engineering gained a Bronze Award in 2013 and is now working towards a Silver Award. Across the UoA the number of female staff has increased and several have been promoted since 2008. Female PhD students, researchers and academics can access further support and mentoring via initiatives such as the Springboard programme as well as the University WiSET group which is chaired by *Noakes* from this UoA.

ii. Research students

Across the UoA various initiatives have been undertaken to maximise the quantity and quality of PGR recruitment including more pro-active marketing via our alumni network and recruitment from undergraduate and Masters cohorts. Applicants are interviewed by two academics either in person or by phone and we actively pursue split-site arrangements through our international activities.

ITS is the largest provider of transport-related postgraduate research training in the UK, and has increased its student numbers from 37 in 2008 to 63 in 2013 whilst SCE has increased from 23 to 60. ITS is host to an international network for PhD training in social science and mobility (The Forge, *Marsden*), which has trained 135 PhD students and ECRs from across Europe since its inception in 2010. The UoA has a track record of industrial collaboration in PhD research with sponsored and CASE studentships during the assessment period from: Arup, BSRIA, Network Rail, the Highways Agency and Sustrans, Jaguar Land Rover, Halcrow NanoCem, Heidelberg Cement and Transport for London. SCE hosts one of the 15 Early Stage Researchers of a Marie Curie Initial Training Network (EU FP7 TRANSCEND project) that aims to improve understanding of water transport in concrete structures and involves close integration of the academic and private sectors.

The training and development of research students falls within the University's *Next Generation Researcher* programme and is delivered by cross-faculty training hubs working in collaboration with central staff development services; this provides access to an extensive programme of research and transferable skills training and personal development opportunities. Research students are given the opportunity to present their research at school and faculty seminars and conferences, and also at the annual University of Leeds PG Showcase Conference. ITS and SCE research students access specialist research training and development through the Institute/School, the University Faculty-led Graduate Schools, relevant DTCs (e.g. Leeds CDTs on Fluids and Bio-energy, White Rose Social Science DTC), and cross-faculty institutes particularly *water@leeds* which has a vibrant postgraduate community. All students are encouraged and supported in attending at least one UK and one international conference.

We integrate our PGR students into our research activities through including them in our research awaydays and research group/institute seminars and supporting them in organising the annual PG Conference for all researchers in the UoA. This broadens their appreciation of the wider research agenda, funding landscape and school strategy. PGRs also produce a termly newsletter and host regular focus groups to get feedback and suggestions. PGRs have representation on various school and faculty committees, such as the School Research Committee in SCE, and the Faculty Graduate School Committee in the Faculty of Environment.

All students have at least two supervisors and all supervisors are required to undergo training in supervision. The university-wide web-based Postgraduate Development Record (PDR) system was introduced in September 2011 and is used to record all interactions between supervisors and students including supervision meetings, training, progress reports and assessment. The latest QAA Institutional Review highlighted the PDR system as an example of good practice. The University monitors its progress in meeting its objectives through participating on a biennial basis in three national surveys: Postgraduate Research Experience Survey (PRES) for research students, Careers in Research Online Survey (CROS) for research staff, and Principal Investigators and Research Leaders Survey (PIRLS). In the 2013 PRES, 83% of PG students in the UoA rated the research skills they developed as 'excellent'.

d. Income, infrastructure and facilities

During the REF period SCE's research spend has doubled with research spend from RCUK sources increasing four-fold mainly as a consequence of new appointments and the strategy of developing larger multi-disciplinary bids (described above). In the last three years (2010-2013) new awards from RCUK have doubled which indicates that this increase in spend will be sustained in the next period. It is noteworthy that this funding is not just from EPSRC, but also includes funding from NERC and ESRC demonstrating our cross-disciplinary strength. The diversity of funding has also been aided by awards totalling £2.8M from the EU and £1.5M from the Qatar National Research Fund. SCE has had a sustained income of over £100k pa from consultancy during the REF period particularly in the area of aerobiology where its environmental chamber offers a unique facility to companies. Over 46 companies have been clients and this is used to develop relationships with users to subsequently involve them in our research and impact activities.

ITS has promoted the strategy outlined above (Section (b)), by focussing its research staffing and expertise in areas which reflect major societal challenges. As a result, it has been able to maintain a broadly consistent level of research income through the REF period, with average research spend of £2.44M (peaking at £3.55M in 2009) and average new awards of £3.01M (again peaking at £4.02M in 2009). ITS has consistently maintained a significant number of longer and larger RCUK and EU grants (41 EU and 23 RCUK grants for RAE 2008, as compared with 38 EU and 27 RCUK for REF 2014). It is impressive that government and industry income has also been maintained (from 17% to 19% of research spend across the REF period) in the face of the significant spending cuts that followed from the 2010 Spending Review. This has included high-impact commissions such as studies on the Business Value of Time underpinning the case for HS2. Consultancy is embedded within ITS's core business and does not generate a significant additional income stream.

In order to support its fundamental science and strategic vision SCE has developed significant laboratory facilities and high-performance computing (HPC). ITS's research is less reliant on major equipment, but it has further developed a major facility, the University of Leeds Driving Simulator (UoLDS) which is one of the most advanced simulators worldwide. Significant investments across the UoA are given below with an indication of each investment's relationship to the vision and strategy above and also indicating where this is support for an ECR:

- Moving and renewing Public Health Laboratories. This included creation of a dedicated Cat II microbiology laboratory, development of Cat II laboratories for water and waste water analysis and development of a molecular biology laboratory for DNA work. £700k. (G1, S2)
- Upgrade of the Soils Laboratory for bio-remediation. £300k (G1, S3).
- Rotary furnace, to build on iRI's research relating the microstructures of cementitious materials to their engineering performance £85k (G1, S2)
- Laboratories for the Energy Technology Innovation Initiative. £1.26m (G1, S2, S4, ECR).
- Ion chromatograph supporting analytical work in waste water and materials research. £55k (G1, S1, S4).
- Building Services Laboratory and wind tunnel. £100k+ (G1, S1, S3, ECR).
- Upgrade to the driving simulator. £250k (G1, S6, S11).
- Upgrade of materials laboratory and casting shop. £430k (G2).
- Upgrade of high-performance computing (64 nodes) dedicated to SCE. £50k. This is complemented by central investment of £1M biennially (4500 cores) and our share in the N8 facility (5312 cores) (G2).

Further planned investments for 2013-15 include new facilities for solid waste research (~£150K equipment and laboratory, ECR), shaking table (£350k with £150k from a partner company, ECR), NMR spectrometer (~£450k) and enhanced microbiology and aerobiology laboratories (£200K aerobiology chamber + ~£300K laboratory upgrade). SCE and ITS operate strategic research funds of £100k and £75k respectively each year on average. This is allocated by the Directors of Research & Innovation and Institute Directors/Research Group Leaders to pump-prime new research activities, especially for ECRs.

e. Collaboration or contribution to the discipline or research base

Research in the UoA is built upon a vision of **interdisciplinarity**. The staff included in this

submission comprise academics from the fields of civil, mechanical and chemical engineering, computing, mathematics, psychology, geography, economics, planning, environmental science, sociology and others. This enables us to partner with other leading scholars in a range of fields to implement cutting edge inter-disciplinary research and deliver impacts to a range of industrial sectors. Highlights (described in more detail above) include:

- EPSRC and NERC funded work on resilience and infrastructure includes Leeds collaborators from the Sustainability Research Institute, Geography and the Business School and collaborators from UCL and the universities of Birmingham, Cambridge, Warwick, Bath, Bristol, Glasgow and Newcastle.
- Through *water@leeds* EPSRC funded work on flood risk includes economists (Sustainability Research Institute, Leeds), social scientists (UWE, Kingston University), business (University of Sheffield), mechanical engineers (Durham University) and geographers (University of Nottingham).
- The NIHR-funded 'On the Buses' study involved a collaboration with public health specialists at the London School of Hygiene & Tropical Medicine.
- The RSSB study 'Evaluating measures to improve personal security and the value of their benefits' involved a new collaboration with criminologists from the University of Huddersfield, which has been carried through into further work for the British Transport Police.
- BASE (Bottom-up Climate Adaptation Strategies Towards a Sustainable Europe) is a €7.6M EU project with social and economic scientists from, amongst others, Aarhus University (Denmark), CMCC (Italy), Helmholtz Center for Environmental Research (Germany), Universidad Politecnica de Madrid (Spain), and FFCUL (Portugal).

Excellence in research requires and attracts **international engagement and collaboration** and in this regard all three institutes are internationally-leading. Since 2008, they have secured a third of the UoA's research portfolio from international sources. Highlights include:

- EcoDriver (led by ITS, value €10.7M, of which €1.96M to Leeds), and significant contributions to SUSTRAIL (value €6.6M, of which €401,975 to Leeds) and SUNSET (value €2.95M, of which €426,197 to Leeds).
- EMIT flu transmission project, $10M total funded by CDC (USA) and involving collaborators in the UK, US, Canada, Australia and Hong Kong;
- NanoCem: a consortium of 23 academic and 11 industry partners from 10 countries across Europe along the USA and Thailand. All are interested in fundamental research at the nanoscale of cement and concrete (annual budget €700k). Black is the Secretary of the Scientific Steering Committee and iRI has been involved in three of its 'core projects', which are funded by the industry partners.
- The UoA's joint coordination (with Mechanical Engineering, UoA 12) of the AMEDEO ITN with partners such as TU Munich (Germany), TU Delft (the Netherlands), Von Karman Institute (Belgium), Rolls Royce and Airbus.
- Research on discrete choice and econometric modelling has stimulated academic papers with some of the world's leading academics in the field, such as Prof. Bill Greene (New York University) (*Wheat 2*) and Prof. Kenneth Train (University of California, Berkeley) (*Daly 1*).

In ITS, *de Jong, Smith (A), Nash* and *Wheat* are visiting researchers at the Centre for Transport Studies, KTH Stockholm, *Nash* is also Research Professor at DIW Berlin and *Hess* is Honorary Professor at the Institute for Transport and Logistics Studies, University of Sydney. In SCE, *Wright* has been appointed as a Visiting Professor of the Chinese Academy of Sciences at its Institute of Mountain Hazards and Environment in Chengdu. *Camargo-Valero* has been appointed Adjunct Professor at the National University of Colombia.

Across the UoA we have a strong track-record of **engagement with research users**. We see this engagement as being broader than just research, offering a partnership which can bring together the training and research needs of different organisations. Furthermore we view this as a symbiotic relationship rather than "them and us". We have Industrial Advisory Boards which include representation from government stakeholders at local, national and international levels as well as from industry (e.g. Halcrow, Vodafone, Yorkshire Water, DfT, Highways Agency, Network Rail). SCE actively engages with two spin-out companies (AquaEnviro and ENCOS – see REF3a) and

hosts the HEIF-funded Water Innovation Hub which develops impact and innovation between the university and users. The UoA has also actively invested in part-time and visiting professors recruited from industry (e.g. *Daly*, RAND Europe; *de Jong*, Significance; *van Vuren*, Mott MacDonald; *Mitchell*, Crossrail); these appointments provide an important link with industry, and a pathway to exploit the innovation potential of the UoA's research. The majority of our research is direct with industry or government end users (e.g. as evidenced by *Case Studies 1, 3* and *4*) and the following are indicative of the UoA's approach:

- The iBuild project involves 25 partners including Arup, CH2MHill, Network Rail, BRE, and Leeds City Council.
- The Nuclear Decommissioning Agency has engaged with geotechnics and materials research and have supported this throughout the REF period with funding of approximately £400k.
- Research on healthcare infection and ventilation, supported by EPSRC, includes NHS Trusts (Bradford, Addenbrookes, Leicester, West Herts), Arup, BSRIA Ltd, Mansfield Pollard Ltd.
- VastNet: Collaboration with Yorkshire Water as part of the Water Innovation Hub developed a tool for the analysis of large water distribution networks.
- Structural optimisation research is carried out in close collaboration with Rolls Royce, Yorkshire Ambulance Service and Parker Hannifin (*Case Study 4*).
- Flood risk research in *water@leeds* involves the Environment Agency, Leeds City Council, JBA Consulting, Halcrow, Arup, AECOM amongst others.
- During the REF period, ITS has delivered commissioned research with or for more than 60 external organisations including:
  - Private sector: AEA Technology, AECOM Ltd., Arup, ATOC, Atkins, Faber Maunsell Ltd., First Group plc, Jacobs Consultancy, Mott MacDonald, MVA, MWH Ltd. (New Zealand), Parsons Brinkerhoff Ltd, RSG Inc. (USA), URS, SNCF (France), TRL Ltd.
  - Public sector (and similar): Chinese Ministry of Railways, Defra, DfT, Cfit, Disability Rights Commission, European Investment Bank, Federal Highway Administration (USA), Greener Journeys, Highways Agency, Leverhulme Trust, National Audit Office, Norwegian National Rail Administration, ORR, Railway Pensions Commission, TfL, World Bank.

Both SCE and ITS have strategies for **international leadership**, and have supported this through strategic funding and annual reviews. Recognition is widespread so we have selected only a small number of specific examples.

Keynote lectures: across the UoA staff have been invited to give 10 keynotes and 27 invited lectures in the USA, China and Europe.

Editorships: *Carsten*: Co-editor-in-chief of Cognition, Technology and Work; *Hess*: Founding editor of the Journal of Choice Modelling; *Marsden*: Editor of Transport Policy; *Watling*: Editor of Transportmetrica B: Transport Dynamics; *Wright*: Editor of ICE Journal of Water Management; as well as a larger number of associate editorships and editorial board memberships.

Prizes: *ITS*: Queen's Anniversary Prize 2009 for Higher and Further Education, in recognition of *'sustained excellence: 40 years impact in transport research and teaching'*; *Black*: Winner of the 2009 Stephen Brunauer Award from the American Ceramic Society for the best paper in the field of cement science*; Daly*: International Association for Travel Behaviour Lifetime Achievement Award 2012, recognising key contributions in the field of travel behaviour research over a period of 40 years; *Horan*: CIWEM award for the Best Paper in Water and Environment Management (2009); *Koh*: Best paper by a young scholar at the 3rd Kuhmo-Nectar Conference, Free University of Amsterdam, July 2008; *Richardson***:** Institute of Materials, Minerals and Mining's Pfeil Award (2009) for a paper published by the Institute of particular merit in the field of ceramics; *Velis*: Winner of the International Solid Waste Association (ISWA) Publication Award 2013, for publication of the most exceptional contribution in the field in 2012; *Wright*: Harold Jan Schoemaker Award (2009) for the most outstanding paper in the Journal of Hydraulic Research in the previous two years (*Wright 2*).

Conference chair: *Black*: organiser of the 2009 Cement and Concrete Science conference*; Hess*: founder and chair of the International Choice Modelling Conference (held 2009, 2011)*; Horan*: Conference Chair of the European Biosolids and Organic Resources Conference (2012).