Institution: University of Huddersfield

Unit of Assessment: UoA11 Computer Science and Informatics

1. Unit context and structure, research and impact strategy

Context and Structure

The Unit's research at The University of Huddersfield is centred in the Department of Computer Science within the School of Computing and Engineering, with all staff entered being members of that department. The Unit has grown significantly in research mass within the census period, with **27.2 FTE** staff being entered compared to 14.4 FTE in 2014. The Unit benefits from strong ties to the School's other department, Engineering and Technology, with which it shares some research groups and funded projects.

Computer Science research submitted to the Unit is organised in several groupings:

1. PARK: (Planning, Autonomy and Representation of Knowledge), the largest and longest running group, with specialisms in Automated Planning and Semantic Web, led by **Antoniou** and **McCluskey**. It developed our Impact Case Study "New AI technologies for enriching and recovering value from urban data with applications to traffic management", and recently opened two application-focussed Centres with external partners, the Centre for Intelligent Transport Management (CITM), and the Centre of Artificial Intelligence for Mental Health (CAIMH).
2. CVIC: (Centre for Visual and Immersive Computing), with specialisms in real-time CCTV analysis, augmented reality and machine vision for smart factory automation, led by **Xu**, who developed our Impact Case Study "Enabling commercial impact from innovations in visual computing".
3. CCS: (Centre for Cyber Security), a recently established Centre with specialisms in applying AI techniques to intrusion detection and access control, led by **Parkinson**;
4. CIndA: (Centre for Industrial Analytics), a recently established Centre with specialisms in IoT and Cloud Architectures, and strong links to CERN, led by **Hill** and **Lane**.
5. CMDS (Centre for Mathematics and Data Science), a joint venture with Engineering and Technology to support mathematical research and teaching within the School, whose members include **Murtagh** and **Titarenko.**
6. TAML (Technology Acceptance and Mobile Learning) research group, whose leaders **Ward** and **Lu** created our Impact Case Study "Enabling better mobile learning for digital skills development".

Development of the Unit's Research and Impact Strategy

The Department of Business Energy and Industrial Strategy first issued a policy document in 2013 outlining their envisioned global grand challenges. In September 2019 this document was updated with primary grand challenges. The University's long term strategy has been based on supporting "areas of strategic research importance" (ASRIs), consistent with these global grand challenges, to foster an interdisciplinary societal underpinning of research throughout the University.

The ASRIs relevant to the Unit must be viewed in a multi-disciplinary context, and include Artificial Intelligence, Cyber Security, Internet of Things and Cloud Computing, Intelligent

Manufacturing and Maintenance, Autonomous Systems, Data Science, Big Data Analytics and Visualisation. The University has published a 5-year strategy map with clear aims in each area of the University's activities (cf Institutional Level Statement - **ILS**). The University's long-term vision has research growth at its core, influencing our objectives below. The **ILS** contextualises this research focus: no academic members of staff are on teaching only contracts, and 100% of all academic staff are to be publishing at international excellence levels. For the Unit's staff this translates to the following strategy with clear objectives:

1) Structure research around Research Centres with an ASRI focus*:* the structure of the Unit into a group of subject-related Centres provides the intellectual support for academics to grow within an environment which fosters collaborative research. The Unit initially had two centres covering ASRIs (PARK and CVIV) at the start of this census period and since then we have sought to expand these to include other ASRIs. This leads to our first 2 objectives:

   - **obj-a)** consolidation and further investment in established research centres.
   - **obj-b)** cultivation of new interdisciplinary areas of both research and impact, in line with University ASRIs.

2) Steer research activity to being pervasive and outward-facing among academic staff*:* actions such as internal funding and new staff recruitment are focussed around the research centre ethos, with all staff being attached to existing centres, or research groups with the potential to achieve centre status. Collaboration with national and international partners will be encouraged to augment internal support and mentorship. This leads to our third objective, which is a direct mapping of the University KPI on academic staff:

   - **obj-c)** increase the number of academic staff active at international level in computer science research to include all academic staff.

3) Focus the activities of Centres on achieving both academic, economic and societal impact: centres primarily must be based on the research of international excellence, from which we will then seek to achieve societal economic impact, utilising an interdisciplinary focus. This leads to our 4th and 5th objectives:

   - **obj-d)** increase significantly the societal and economic impact of our research activities both through established and through new research centres.
   - **obj-e)** increase significantly the academic impact of our research activities both through international collaboration and quality and quantity of outputs.

Quantitatively, we equate the success of our strategy and the achievement of our objectives to the doubling of metrics (funding, PhDs, internationally excellent publications, etc) between 2014 and 2021, and commit to a similar increase for the next period.

Current Research Growth and Vitality

To measure whether we are succeeding, firstly we can compare our performance using the aspirations within the REF5 template for REF2014, and secondly, we show how during this census period we are meeting our strategy objectives.

Our UoA 11 REF5 submitted to REF2014 stated that we would double our research outcomes by the end of the subsequent REF period. We have achieved these aims in good measure as follows:

- the number of PhDs awarded *per year* has more than doubled
- the amount of external research income *per year* has more than doubled
- the FTE of staff being submitted to REF2021 has almost doubled - 14.4 to 27.2
- the number of research students enrolled in July 2020 was at least 50% higher than the beginning of the current census period.

As an illustration of how we are meeting objectives **obj-a)** and **obj-e),** during the census period, at least 44 outputs at CORE A / A* rated Artificial Intelligence conferences were published by University staff from the PARK research centre alone. The table below details the year (first row), the conference venues (second row) and the total publication numbers each year (third row), with multiple papers at the same venue also shown. This gives clear evidence of the vitality within PARK's research environment which is leading to research of the highest quality.

2014	2015	2016	2017	2018	2019	2020
3*ICAPS	AAAI, 3*IJCAI, IROS	2*AAAI, ICLP, IEEE-CDC, KR, IJCNN	AAAI, 2*ICAPS, IJCAI, 2*K-CAP, ESWC	2*AAAI, 2*ICCS, 2*IEEE-FUZZ, ICLP	AAAI, ICAPS, AAMAS, 2*ICCS, 4*IEEE-FUZZ, K-CAP	AAAI, 2*ICAPS, ICLP, ICCS, IEEE-FUZZ
3	5	6	7	7	10	6

To illustrate our progress on **obj-b)**, we started the assessment period with existing strengths in Artificial Intelligence and Visual Computing (PARK, CVIC). Initial applications of automated planning to security led **Parkinson** to create the CCS which now includes areas of block chain, cryptography, and network security, and has supported the creation of new degrees in BSc Cyber Security with Computer Science and MSc Cyber Security and Digital Forensics. New professorial appointments **Hill** and **Lane** initiated research in cloud architectures and IoT and their application to complex industrial data, and forged the creation of the CIndA. New initiatives also include interdisciplinary research, for example two new Computer Science Department Professorial appointments **Murtagh** and Lee (Lee is submitted to UoA 12) have led to the establishment of the CMDS, a joint venture with Engineering. The School's composition of Computing and Engineering has also led to interdisciplinarity, for example 4 staff in PARK are being submitted to UoA 12. An exemplar illustrating the effect of our strategy's focus on interdisciplinary research is the new £1.8M Smart Rolling Stock Maintenance project funded via the European Regional Development Fund and supported by the Northern Powerhouse. The project is led by the University's Institute of Railway Research (IRR) (UoA 12) in collaboration with PARK, and involves a range of key industry partners including Northern Trains Ltd, Porterbrook and Unipart Rail over the course of its three-year run (2020-2023). PARK leaders **Antoniou** and **McCluskey** are Co-Is with responsibility for delivering automated planning and scheduling solutions for rolling stock maintenance management, autonomy for the robotic devices involved in maintenance, and for ontology development underlying system and process models within maintenance depots.

With regard to **obj-c)**, we can point to the body of staff being submitted to REF to indicate degree of pervasiveness of research culture through the department: of academic staff in the Department not REF-submitted, either their research falls into a different Unit, they are yet to secure a PhD, and/or they are at a teaching assistant or research assistant status.

We are delivering on **obj-d)** as evidenced by our three Impact Case Studies (named above, in Transport Management, Mobile Learning and Computer Vision and Visualisation), as well as delivering significant impact to Health (**Antoniou**) and Security (**Parkinson**), detailed in the sections below.

Support for Research Growth

Researchers apply for funding via a wide variety of mechanisms as shown by our REF period funding profile in Section 3. To help researchers engage in these activities University investments in the School include a Research and Business Development team (the RBD team) which include two Business Development staff, a Research Development Manager, and an Impact Officer. Coupled with the growth of pre- and post-award teams to support academics/researchers in securing and delivering new research projects, these investments in supporting infrastructure have helped to deliver research income and consequent research impact (described in more detail in Section 3 of this document). The Unit (primarily though the RBD team) also draws heavily on the University central resources to support technology transfer activities, as well as the growing legal and contracts teams that help facilitate contractual/collaboration arrangements with industry partners to achieve impact.

Three particular factors guarantee the sustainability of our progress in growth of research and impact:

Institutional Support: Over the census period, the University has invested ~£7.9M institutionally in supporting delivery of its Research Strategy (via the "University Research Fund" or URF), and examples of the effectiveness of these funds are given in this document. This will continue into the next research period (cf **ILS**).

New Application-Focussed Initiatives: 2020 saw the creation of several new, exciting initiatives in terms of interdisciplinary positioning of the Unit's research outputs:

- the creation of CITM (cf Context and Structure), a collaboration between members of PARK and staff from Kirklees Local Council, SimplifAI Systems Ltd, to deploy AI technology to autonomously perform urban transport management;
- the creation of CAIMH (cf Context and Structure), a collaboration between members of PARK and the University's School of Human and Health Sciences and South-West Yorkshire Partnership NHS Foundation Trust, in the application of AI techniques to ADHD, autism and suicide prevention;
- the coordination of a Framework Research Collaboration Agreement by members of CindA with CERN's Beam Instrumentation Group to deploy novel opto-electronic sensing and associated signal detection and processing.

New Significant Research Awards: As well as the interdisciplinary £1.8M Smart Rolling Stock Maintenance award mentioned above, in 2020 **Vallati** received a prestigious UKRI Future Leaders Fellowship award (FLF) entitled "Artificial Intelligence for Autonomic Urban Traffic

Control". The FLF, in partnership with Transport for Greater Manchester, Kirklees Council, and SimplifAI Systems Ltd, will last four years, will last four years initially with the opportunity to extend to seven years, with a grant of £1.4M.

Research Governance

Research activity in the School is overseen by the School Research and Enterprise Committee (SREC). Membership of SREC includes all professors and others in the School with a strategic role. Day to day research management including allocation of University funding and oversight of REF activity is coordinated by the School-wide REF Operations Group. In the Unit, Centre Leaders are members of the SREC and the REF Operations Group, and with the Unit Co-ordinator and Head of Department are responsible for developing Unit-level strategies such as those in this document.

Open Research

The Unit is committed to ensuring publicly funded research is openly accessible, transparent, collaborative and efficient. We use systems the University has invested in to promote open research and open access to research outputs, and research data management (e.g. Elsevier's PURE information system). Where conflicts may occur (e.g. industry funded research, new IP requiring protection prior to publication) support is provided to researchers from the RBD team to proactively manage issues within the context of the Institution's policies.
An example of open access is the Phishing Database set up by **McCluskey**'s research student Rami Mohammad in the UCI Machine Learning repository, with 100-200 downloads every month in the last year as evidenced in http://eprints.hud.ac.uk/id/eprint/24330/.
An example of open research is **Antoniou**'s EU-funded project Semdata www.semdata-project.eu/ won under the FP7 Marie Curie International Researcher Exchange Scheme, in the area of semantic data management.

Research Integrity

The Unit is committed to having a culture that promotes research integrity, in line with the University's commitment to the Concordat to Support Research Integrity. An institutional Code of Practice for Research provides the framework under which researchers operate, and all new projects and proposals are subject to ethical review and approval as part of a standard sign-off process prior to project approval. Where specific ethical concerns may exist, the School Research Ethics Committee provides guidance and support to researchers, as well as a link to the Institution's University Research Committee which has overall governance of research integrity. As an example of this approach, **Antoniou** recently obtained IRAS approval for a project he is leading with South-West Yorkshire Partnership NHS Foundation Trust on suicide risk assessment.

2. People

Staffing Strategy

Staffing strategy within the Unit has underpinned our research strategy, with an ambition to grow high quality research with impact. Therefore, a successful research track-record is a pre-requisite for all new academic and researcher staff appointments, with all expected to have a PhD, and to have a research record that fits into our Centre-based culture (at the time of the

census, 90% of computer science academic staff had PhDs). In the case of senior appointments there is an expectation that track-record will include significant high-quality research outputs, evidence of securing competitively awarded research funding, and of successful collaboration with external partners. In the case of early career appointments, evidence of the potential to develop these outputs is a key element of the recruitment process. In order to achieve the increase in research over this REF period we have applied this strategy, increasing the number of full time Professors from 3 at the end of REF2014, to currently 9 Professors, and making in total 13 new appointments out of the 29 (head count) submitted staff. These new appointments have built up strength in existing Centres, and enabled creation of new Centres such as the CindA and CMDS. Over the REF period our REF2014 QR funds and Central internal research funding support (URF) have been used predominantly to pay for research fellows to assist research centres deliver on their research growth. Three of these research fellows initially supported by internal funding are now members of the Full Time Lecturing staff (**Chen-T**, **Tachzimidis** and **Bargiannis**).

The University introduced a Research Excellence Scheme (RESS) in 2016 which aims to provide opportunities to excellent research staff from other Institutions to join the University on indefinite contracts. During the REF period this has amounted to two professorial appointments in this Unit, linked to specific ASRIs: **Murtagh** (Data Science) and **Lane** (IoT and Cloud Computing). **Murtagh** subsequently formed the cross-school Mathematics Group which has added substantially to teaching and research and supports the CMDS.

Staff development strategy for all staff pursuing a career in research

In terms of staff development and advancement, the Unit adheres to the national Concordat to Support the Career Development of Researchers, which sets out the seven key principles for funders and employers of researchers in the UK. The Unit aims to support staff according to these principles whatever their career stage and believes a supportive culture enhances researcher performance, improves staff retention, and aids recruitment of both staff and post-graduate students. All staff undergo an annual personal development review/appraisal which includes consideration of research performance and planning, including identification of specific training and development needs/opportunities. Research performance is an important metric for successful career progression of all academics, with indicators such as research outputs, income and successful Post Graduate Researcher (PGR) supervision essential for progression to senior academic/researcher positions. During the current REF period 4 staff were promoted internally to Professor (**Faber**, **Ward**, **Crampton**, and **Xu**) and 3 to Reader (**Parkinson**, **Vallati**, and **Venters**).

In terms of development and training, the Unit has access to a large institutional staff development portfolio which is mapped against the Vitae Researcher Development Framework. The Unit has actively engaged with the University's initiative – for example, in an initiative with the Chartered Management Institute for senior and mid-level staff to achieve Level 7 management qualifications and obtain Chartered Manager status. In the REF period 5 senior academics – **Hill, Antoniou, Carter, Ward,** and **Crampton** in the Unit have so far achieved this goal.

The School's RBD team has also established a Researchers' Network (aimed primarily towards early career staff but open to all) and are running regular seminars and workshops on topics of interest and value to the community (e.g. the funding landscape, IP protection and exploitation, how to build industry partnerships, maximising impact from research, etc.). These are designed

to supplement centrally provided training and are practical/operationally focussed, encouraging researchers to share their own experiences and challenges with colleagues. The team are at the heart of support for staff: their effectiveness was recognised by the University as they won the Outstanding Contribution to Research and Innovation Support award in 2015.

Support for Career Development of Researchers

All new academic staff appointees are provided with an introduction to the various support structures with regards to research such as Pre-Award, Post-Award, PURE and the RBD team. Each member of staff is assigned a mentor, and a research group (normally part of a Research Centre). Staff benefit from mentoring within the context of their respective research groups, all of which hold regular (typically weekly) seminar series where researchers can present and discuss their work with peers and their senior group members and by providing help as appropriate to identify key collaborators, establishing likely funding sources and assisting in drafting bids. Staff early in their career are actively encouraged and supported in gaining experience of supporting undergraduate and/or postgraduate teaching activities. Both **Parkinson** and **Vallati,** in particular, achieved success supported by the Department's development infrastructure: both won Researcher in Residence awards from The Catapult Network. Within the University, **Vallati** was nominated for Outstanding Early Career Researcher (2015), and **Parkinson** won University research supervisor of the year 2020.

There is much evidence for the success of our early career support: all three ECRs from the Department submitted in REF2014 (**Vallati, Batsakis** and **Chrpa**) now have teaching responsibilities, and two of them have senior positions - **Vallati** is Reader in the Department, and **Chrpa** is now Assistant Professor at Prague Technical University. **Parkinson** was an undergraduate and doctoral student at The University: subsequently he became a lecturer and has attained Readership status, and now is leader of the CCS. The University runs interdisciplinary sandpits which are aimed particularly to encourage early career staff, and have supported **Bargiannis**, **Valatti** and **Tachmazidis.** The School has a Research Development Manager (Dr David MacDougal) to guide staff in their early career on the path to grant application success.

The School supports Sabbatical Leave and Leave of Absence where it would enable an academic to carry out a specific programme of research and development, or the completion of a commissioned book or research paper or the preparation of a major research grant application. For example, **Ward** developed the iDEA method during a 12-month sabbatical leave within Buckingham Palace, leading to TAML's Impact Case Study.

The Unit takes advantage of the University's Collaborative Ventures Fund (CVF) which provides up to £2,500 of internal funding for academics to work on short feasibility projects for external companies at no cost to them. This has led to key relationships being developed resulting in KTP projects, sponsored PhDs, Innovate-UK funded projects, with more details in Section 4.

Equality, Diversity and Inclusivity

The Unit is committed to creating and maintaining a culture of research diversity and recognises that a positive and supportive environment where researchers from all backgrounds can flourish will significantly support the Unit's future ambitions.

Similarly, the University is committed to EDI and has robust policies and codes of practice to guide and support staff and PGRs. In 2020, the University signed up to the Race Equality Charter (REC) and completed the Investing in Ethnicity Maturity Matrix to inform the REC action plan. In 2018, the University was accredited as a Disability Confident Employer and was a signatory to the Mindful Employer Charter; it is also a Stonewall Champion and participated in the Stonewall Equality Index in 2019. The University has four staff networks (LGBTQI+, BAME, Women and Disability) run by members with support from the University EDI Officer. The University has Athena Swan Bronze accreditation and the School in which the Unit sits is also working towards an Athena Swan Bronze award.

EDI is also a priority within the University's REF2021 Code of Practice, and a detailed Equality and Impact Assessment (EIA) has been completed as part of the process of selecting staff outputs for inclusion within the REF assessment process. EDI influences our behaviour in the Unit, for example it is mandatory for senior staff to undertake the University's on-line 'unconscious bias' and 'diversity in the workplace' modules.

An equality impact assessment was undertaken for the Unit and was used in the final identification of output pool prior to submission. The most significant factor in UoA11 affecting SRR/IR selection was postgraduate qualification, for example more than one third of staff who were identified as not-SRR are still studying for a doctorate degree.

Regarding PGR students, personal learning support plans (PLSP) are developed for all who require one. This is written following an interview between the PGR and the central University Disability Team. Support is provided for those who declare a disability and is determined by the content of the PLSP, whether this be specific display screen equipment or support from the School Guidance Team.

PGR Student Recruitment, Development and Progression

Student Recruitment

At the end of the census period the Unit had 64 doctoral research students enrolled (43 FT and 21 PT, a rise of 50% from the start of the census period), with nearly two thirds of them being international. Recruitment of PGRs follows a robust recruitment process with all projects/potential projects being advertised through a variety of channels, including the University's main application platform 'Coursefinder'. The Unit follows the University wide recruitment process for all of its doctoral research students, which includes a review of the proposals by the research group/supervisor, interviews, completion of a Pre-Enrolment Form and ensuring all the relevant checks are completed before the applicant is offered a place at the University.

Internal funding has been provided to accelerate growth in research and enterprise and one scheme which is available to potential research students is the fee waiver, where University fees are fully or partly waived on the basis of merit. Since the beginning of the census period, 46 fee waivers have been awarded to PhD and Masters by Research students. Examples of external funding include **Murtagh's** 4-year EPSRC NPIF award "Mathematical Foundations of Optical Nano and Micro Mass Spectroscopy" which commenced October 2018. The Unit also benefits from opportunities to collaborate within our sister engineering department's EPSRC Doctoral Training Programme, which fully funds a number (currently 12) of PhD studentships each year.

Details of monitoring and progression-support mechanisms:

All doctoral research students are required to submit a Research Plan and Skills Audit after three months (pro rata for part time and after two months for Masters). The purpose of this is to enable students to develop a clear plan for their research project, to explore the skills and training which will be required, gain any required ethics approval, to perform an initial literature search and from this to identify their research question.

Records of supervisions are kept by both students and supervisors in the University's SkillsForge platform. Progression vivas are held after 9 and 21 months, for which students are required to submit an annual report detailing their progress, and then give a short presentation to a panel consisting of two academics from the subject area who are not involved in the student's supervision (this allows also for frank discussion of the student's level of satisfaction with the supervision provided). For progression to be approved, the examiners must be satisfied that the student has made sufficient progress both intellectually and in terms of timescale for completion. Research training needs form part of the discussion in these vivas.

Continued support in the preparation for these milestones is provided primarily by the supervision team; generally comprising of a main supervisor, second supervisor and personal tutor. Additional provision is available within the Unit by our Academic Skills Tutor and from a central provision within the Academic English Centre, which provides a variety of targeted workshops and courses. Organised courses on areas such as academic writing, plagiarism and reviewing literature are complemented by tailored one to one support if required. For example, the five half-day sessions of the Essential Journal Writing Skills Course are mandatory for all full-time doctoral research students and introduces the art of producing original research articles with a focus on crafting introductions and reviewing literature with detailed guidance on paraphrasing, referencing and avoiding plagiarism. All doctoral research students receive an electronic newsletter which provides an overview of the upcoming courses and workshops.

To ensure that the voice of the doctoral research student is heard and considered, the Unit runs a PGR Student Forum twice per annum with membership comprising of the Director of Graduate Education (DoGE), four student representatives (across all Units within the School of Computing and Engineering), one Student's Union representative, two academics, one library representative, one technician and one secretary. The Forum has a Terms of Reference and is formally recorded. All School and University Committees have representation from a doctoral research student, again to ensure the voice of the PGR is heard and considered.

In addition to the high-level academic support and development as described above, examples of additional resources available include training on research ethics and integrity in our on-line Researcher Environment, our Teaching Assistant Preparation Programme and the University's Careers and Employability Service. Research students are encouraged to engage with internal events such as our Three Minute Thesis competition and the annual PGR Conference as well as presenting at external conferences and academic meetings. The Unit provides financial support to each doctoral research student in the form of a £300 contribution towards a national conference and £500 towards an international conference, through our Conference Presentation Fund. For an example of its effectiveness, during the UK PlanSIG Workshop in 2020, out of the 11 papers presented, 3 had current PhD students in PARK as first authors (R.Reba, S.Mund and H.Jaazaa).

3. Income, infrastructure and facilities

Strategy for generating income

Utilise the Research Centre structure: the Research Strategy detailed in the first section of this document hinges on growth in research and impact. The structure of the Unit into a set of ASRI-related Centres provides the intellectual support for academics to grow within an environment which fosters mentorship and collaborative research. The success of the PARK group is evidence of this, and the other, new Centres are likewise providing the same kind of environment. As an example, the CCS became a standalone research centre in 2017 (formally the academics were part of PARK research centre). This has resulted in more focus on cyber security research and a total of £260k of income has been generated by **Parkinson** via a variety of different grants and sources including UKRI, government, Innovate UK, KTP and industry investment.

Reinvest Research Income into Centres: in order to help grow research and research income within each centre, the School has a strategy of reinvesting any research surpluses back into that research centre. This has supported **obj-a)** in our strategy, with research centres (particularly PARK) being enabled to grow their resources by employing new research fellows and offering PhD bursaries.

Provide close mentorship and bid development advice**:** as covered in Section 2 above, the School and University have a range of support mechanisms for supporting grant bidding, particularly those relatively inexperienced. With 13 new academic appointments in the census period, developing the bid-winning potential of each member of staff is of paramount importance. For example, **Vallati**'s successful bid for a UKRI Future Leaders Fellowship started years before with mentorship and subject assistance within PARK, as well as the benefit of international collaborations. The identification of this particular mechanism was recommended and assisted by our Research Development Manager (see Section 1) with industrial connections cemented by our RBD team. While every external bid in the School has to be peer reviewed and signed off before submission, the development of **Vallati**'s bid in particular was monitored, reviewed and supported by his mentor, the Research Development Manager, and other School-wide senior staff, to maximise his chance of success.

Develop and grow commercialisation opportunities: the School and Unit has been increasing support for achievement of societal impact (strategic objective **obj-d)**), and the development of more user-led research. This is consistent with University Strategy map KPI of 15% of research outputs by 2025 to be generated in collaboration with end users. Progress has been facilitated by the increased support within the RBD team (with two new appointments since 2014) as well as the development of a Research Finance Support Team. This extra support has been particularly important in the commercialisation of our Urban Transport Management research (more details in PARK's ICS). Also, **Lane** has secured £50k from the ERA foundation and £30k from the Royal Academy of Engineering to develop both education activities and technical engagement with manufacturing SMEs to support them with the adoption of Industrial Digital Technologies.

Submitted Unit's Income

UoA 11 has had a steady portfolio of research income year on year underpinned by a combined investment in new academics, new research centres, research support infrastructure, mentoring and development of academic staff. The research funding for the census period has increased

compared to the last REF period by a **per-year** factor of more than two (total income for the REF2014 period was £589K and total income for the current census period is £1,983K).
We continue to maintain a strategy of developing a mixed portfolio of grant funding resulting in a balance between Industry, UKRI, EU and Government funding. While EU income has declined, commercial income has increased, and with recent funding successes, Research Council grant income should also rise to compensate for this (see Table below).

There has been a significant increase in bids during this REF period from a greater number of academics. Our bidding portfolio has also increased from £2.5M worth of bids in academic year 15/16 to £3.7M of bids in academic year 19/20. This aligns with the increased support both centrally and with the School to facilitate the bidding process, provide training and support and the increased academic mentoring with research centres.

Percentage Income per Annum and Income Sources								
	2013/14	**2014/15**	**2015/16**	**2016/17**	**2017/18**	**2018/19**	**2019/20**	**Total**
BEIS Research Councils, The Royal Society etc	25.9%	41.9%	63.7%	7.0%	6.9%	14.2%	12.5%	**22.2%**
UK-based charities (open competitive process)	0.0%	0.0%	0.0%	0.0%	0.0%	3.3%	19.7%	**3.3%**
UK central government bodies/local authorities	10.8%	2.7%	6.7%	25.2%	61.4%	55.1%	19.7%	**29.8%**
UK industry, commerce and public corporations	0.0%	0.0%	11.5%	29.2%	14.7%	14.3%	40.2%	**15.6%**
UK other sources	0.0%	0.0%	0.0%	9.0%	0.0%	0.0%	0.0%	**1.0%**
EU government bodies	63.4%	55.4%	18.1%	29.5%	17.0%	13.2%	6.1%	**27.9%**
EU-based charities (open competitive process)	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.8%	**0.3%**

Exemplars of Success in Grant Income and Commercialisation

As part of growing commercialisation opportunities in the Unit, five Knowledge Transfer Partnerships have been awarded within the census period (growing from zero) and totalling £800K of current and potential future research grant income. In order to continue growing the

number of KTPs, a strategy of maintaining a portfolio of three KTPs running at any one time was agreed. By the end of this REF period the Unit has successfully achieved this outcome (current KTPs with ValueChain, Brandon Medical and Andel Ltd).

Alongside the KTP target, there has been a focus on working with our company partners to apply for Innovate UK grants and to look at commercialisation opportunities. An exemplar is **McCluskey** and **Vallati**'s collaboration with Transport Consultants which led to grants of progressive size: starting with an internal CVF of £5000, this led to a consortium project including British Telecom and Transport for Greater Manchester winning funding from the Innovate UK Competition "Solving Urban Challenges with Data" (2015 - 2016). This resulted in a Transport-Consultants-led Innovate UK First of a Kind collaboration of approximately £1M, of which PARK secured £150,000. This further led to the establishment of a joint venture company (SimplifAI Systems Ltd), between PARK and the Transport Consultants, of which the University owns 15% of shares, and the establishment of the collaboratively-run CITM detailed in Section 1 above.

Infrastructure and facilities

The School has invested in a dedicated state-of-the-art space for PGR students including hot-desking facilities for over 50 students, lockers, meeting rooms, chill out area, kitchen facilities, and a dedicated admin team. A new Technical Services Manager has also been appointed bringing all the technical and IT technicians under one management structure resulting in more joined-up support for our researchers.

Staff and research students have access to a wide range of computer facilities, humanoid and other robots, servers and specialist computer software. For example, the deterministic track of the 2014 IPC (International Planning Competition) which was organised by **Vallati**, **McCluskey** and **Chrpa**, and attracted 86 entries (i.e. planning software) from all continents of the world, would not have been technically possible without the use of the School's inhouse high performance computing facilities. Apart from the contribution to the discipline, this infrastructure provided the foundation for a huge amount of empirical investigation, resulting in a substantial article by the organisers in Knowledge Engineering Review 2018 and an earlier AI Magazine article that together have attracted well over 100 google cites by December 2020.

The University's Innovation Centre (the "3M BIC") is housed opposite our Department's building and contains an Industrial Digital Technology demonstration laboratory. **Lane**, for example, has used this facility to support his ERA Foundation funded initiative, in collaboration with National Physical Laboratory staff, to engage with manufacturing SMEs to foster the adoption of Industry 4.0 technologies.

4. Collaboration and contribution to the research base, economy and society

Overview of Support for Collaborations

Collaborations in the widest sense are an essential ingredient in achieving all 5 of our research strategy's objectives, where the Unit is seeking to rapidly raise its research profile nationally and internationally. Consequently, as well as winning direct external funding, we have at our disposal both Central University mechanisms and School mechanisms to help us deliver them. These collaborations range world-wide, are often interdisciplinary in nature, and often provide the basis for the academic and societal impact of the pioneering research undertaken within the Unit.

Our School's impact strategy is strongly aligned to the Unit's overall strategy (c.f. **obj-d** in section 1). Its aim is to foster close collaboration with industry partners to accelerate knowledge transfer and the adoption of new technologies to deliver impact. This includes extensive support for the use of funded mechanisms such as KTPs, Innovate UK Collaborative R&D programmes (e.g. SMART grants). Seed-funding grants such as the CVF detailed in Section 2 are often used to lead to these larger collaborations, being the prime collaborations with research users (e.g. the PARK's involvement in **Urban Transport Management** started using a University Collaborative Funding Voucher of £5000 and led to over a million pounds of investment in this area from Innovate UK and Venture Capitalist funding – more details are given in PARK's Impact Case Study "New AI technologies for enriching and recovering value from urban data with applications to traffic management").

For collaborative support in general, the Unit has received:

- **Support for collaboration from the University Centre.** URF is competitively obtained and is predominantly used to support collaborations. URF funds have been used for promoting interdisciplinary groups (e.g. CAIMH led by **Antoniou** detailed below), and for promoting international collaboration (e.g. the Robotics Centre led by **McCluskey** detailed below). For example, URF strand "Research Networking Fund" supports full-time and part-time postgraduate researcher visits to centres of research excellence.
- **Support mechanisms for collaboration from the within School** include use of support staff (described in the People section above), and the use of funding devolved from Quality Related income (for example research fellow **Franco** was funded via QR to support PARK's Urban Transport Management research).

Exemplars of Collaboration - Academic Networks led by Unit Staff

The EU-funded project Mirel (https://www.mirelproject.eu/) under the H2020 Marie Sklodowska Curie Research and Innovation Staff Exchange scheme in the area of AI for law, was led by **Antonoiu** as PI. The project was important in advancing the research agenda and state of mining and reasoning with legal texts and is currently producing a reference book on AI and Law. University of Huddersfield researchers visited institutions including University of Bologna, University of Luxembourg, CSIRO, Stanford University and Zhejiang University, and hosted international researchers and research students from China, Australia and Argentina. For example, **Vallati** visited the Universidad Nacional del Sur (Argentina), leading to a jointly written Scimago Q1 journal publication. Funded by Mirel, he also gave invited talks on knowledge engineering for AI Planning at the University of Tokyo, Japan (June 2019), and at Universidad Nacional del Sur, Argentina (July 2017).

The EU-funded project Semdata www.semdata-project.eu/ under the FP7 Marie Curie International Researcher Exchange Scheme, in the area of semantic data management, with PI **Antoniou**, was important in advancing the research agenda and state-of-the-art of open data curation and quality, stream data querying and reasoning with big data. University of Huddersfield researchers visited international institutions such as Stanford University, Wright State University and RMIT, and hosted international researchers and research students from China, Australia and Ukraine.

The COST European Network in "Autonomic Transport Support Systems" (TUD 1102, 2011 - 2015), chaired by **McCluskey**, had the participation of scientists from 24 European countries.

Departmental staff and students participated through scientific visits and participation in workshops and competitions. The main outputs of the network were an edited, refereed book "Autonomic Transport Support Systems" published by Springer (DOI 10.1007/978-3-319-25808-9), two international competitions, two training schools, various focussed workshops, and 45 short term scientific visits. As an example of the latter, in June 2015, the Network funded **Vallati** to visit the TU Delft university in The Netherlands. The visit led to a number of subsequent publications, including one in the AAAI-2016 conference, and eventually led to a patent described below filed by SimplifAI Systems Ltd.

University Research Funding supported the Department's Robots Research Initiative [2014-2017] with £86,986 supporting a sequence of high profile international collaborations, underpinned by purchases of humanoid robots and support staff. The project funded the visit of Dr Tiago Vaquero from MIT/CalTech in June 2016 to collaborate on robot research; in 2015 **Chrpa** visited the Robotics labs at LSTS, University of Porto, and the Icelandic Institute of Intelligent Machines (IIIM), applying PARK's expertise in Automated Planning to robotic applications. The visits led to joint publications, including a publication at the premiere robotics conference IROS, and joint Huddersfield - MIT organisation of the 2016 international competition ICKEPS [https://ickeps2016.wordpress.com/] at ICAPS 2016, London.

Exemplars of Collaboration - Interdisciplinary Research led by Unit Staff

Lane is Technical Coordinator for a Framework Research Collaboration Agreement with CERN. This has led to three PhD projects between CERN and CIndA, and a successful bid for EU ATRACT funding for €100k in total. He holds a Visiting Scientist post at CERN in the Beam Instrumentation Group in the Beams Department and works on novel opto-electronic sensing and associated signal detection and processing for the CERN accelerator complex. He is also the lead investigator of Huddersfield's association with the ATLAS experiment at CERN as a Technical Institute providing software, simulation and system design support to the trigger and data acquisition activity. Huddersfield is the first UK university to be accepted by ATLAS as a Technical Institute.

Antoniou received support from the University Research Fund to drive interdisciplinary research across campus, with the aim of establishing an AI Institute. Based on this funding, he was able to reach out and establish a lasting working relation with South-West Yorkshire Partnership NHS Foundation Trust. Co-funded initiatives between the University and Trust developed world-leading AI solutions in the areas of suicide risk assessment and adult ADHD diagnosis, while a new initiative started in 2020 towards developing an AI algorithm for diagnosing autism. Potential benefits include more accurate prediction of suicide and cost-effective decision support solutions for diagnosing ADHD and autism providing significant cost savings to the NHS through higher productivity per specialist clinician. These cost reducing effects are also the foundation for funding received by Research England through Grow MedTech towards possible commercialisation of the ADHD solution.

McCluskey was PI and overall manager of the EPSRC project "Machine Learning and Adaptation of Domain Models to Support Real Time Planning in Autonomous Systems (EP/J011991/1 and EP/J011800/1, 2012 - 2016), collaborating with Prof Austin Tate of the University of Edinburgh, and Schlumberger at Schlumbeger-Gould research Centre at Cambridge. This was funded as part of the first tranche of the EPSRC/Industrial initiative in Autonomous and Intelligent Systems (2012-2017), aiming to create a sustainable world-leading

robotics and autonomous systems industry in the UK. It supported a network of nine projects across 16 universities. Industrial partners in the network were BAE Systems, Schlumberger, National Nuclear Laboratory (NNL), Sellafield Ltd, Network Rail, SCISYS, DSTL and the UK Space Agency. Many outcomes for Huddersfield followed including McCluskey's further work with the DSTL on the future of autonomous agents (http://eprints.hud.ac.uk/id/eprint/31984/).

As well as the above, the £1.8M ESIF grant "Smart Rolling Stock Maintenance" (2019-2023) detailed in Section 1 is a good example of such interdisciplinary research.

Exemplars of Collaboration - Research Users and Societal and Economic Impact
The Unit has won 5 Knowledge Transfer Partnerships since 2014, details of the most recent 4 follow:
Impact via Knowledge Transfer Projects:

- **Axia Digital / Citizen Connect Ltd (PN-10103***)*. This KTP led to the development of a new secure and customisable architecture for producing bespoke digital portfolio solutions, which are being used by clients with c.600k users worldwide. (PI: **Parkinson**)
- **Mainstream Measurements Ltd (PN-10565)** This project culminated in the release of the Mainstream MODBUS communications adapter, which provides a secure communication interface for remote data acquisition, control, and integration. The contribution of the Associate (Sean Howson) to the project won the UK KTP's ``Future Innovator'' award in 2019 http://wateractive.co.uk/products/120k_rd_project_opens_up_markets_worldwide_for_water_flow_measurement_company. (PI: **Parkinson**)
- **Valuechain.com (PN-11073).** This three-year programme will provide the company with the capability to embed machine learning algorithms into its supply chain management software. Based on the KTP's work, Valuechain have secured a new Innovate UK / Aerospace Technology Institute project in collaboration with Digital Catapult and Airbus. (PI:**Crampton**)
- **Brandon Medical (PN-10961)** This joint work with our Department of Engineering Technology is aimed at improving product and service quality driven by the use of automation and data analytics in the manufacture of medical lighting and healthcare devices (Co-I: **Hill**).
- Building on the sensing and data processing work carried out at CERN within **CIndA,** KTP has been won with Andel Ltd. This is yet to commence, but aims to develop a novel leak detection cable and associated signal processing to physically locate leaks across a wide range of scenarios including data centres and buried pipework. (PI: **Lane**)

Impact Summary within Our Impact Case Studies
PARK's ICS (**McCluskey** et al) demonstrates impact with research users British Telecom, SMEs and Transport Authorities. CVV's ICS (**Xu** et al) work in computer vision, visualisation, machine learning, and their software found extensive use in real-world tasks such as tracking and semantic segmentation. TAML's ICS (**Ward** and **Lu**) shows that their iDea Portal and WRS technology has led to impact in educational settings across over 190 countries, including being used to teach the UK computing curriculum in schools.

Collaborations and Societal Contributions in Health:
Antoniou's established collaboration with the NHS Foundation Trust (SWYPFT) referred to above, has led to AI solutions for adult ADHD diagnosis is being used in the clinical service of SWYT, and has received funding from Research England, through Grow Medtech (a Yorkshire

universities collaboration funded by Research England Connecting Capability Fund), towards possible commercialisation. Completed research and progress reports have been published in relevant journals and conferences in mental health (e.g. Crisis journal) and computer science (e.g. Applied Artificial Intelligence). **Vallati** established collaboration with the Hospital Policlinico Gemelli (Rome) and with the Brescia Hospital in the area of process mining for healthcare. This interaction led to a number of publications, and to the release of an R package called PmineR (http://www.pminer.info/progetti/website/main.php) that can be freely used for process discovery and conformance checking.

Public Engagement:

The UoA is committed to the Concordat for Engaging the Public with Research, with the University Centre providing an Engagement Fund for training in public engagement. Specific examples include:

- **Vallati** uses his research expertise to write articles in Magazines such as The Conversation (https://theconversation.com/will-ai-take-over-quantum-theory-suggests-otherwise-126567) and in Academic blogs (http://blogs.hud.ac.uk/academics/2020/march/will-driverless-vehicles-take-over/).
- **McCluskey** delivers a talk each year to local Schools based on his research in Autonomy entitled “From Self Driving Cars to Thinking Robots – the advent of Autonomous Intelligent Systems”.

Wider public engagement by researchers has primarily been through formally organised events such as University European Researcher Nights in 2016 and 2017 (where over 3,000 members of the public attended the University for open events showcasing our research) delivering presentations and, more importantly, hands on activities. Researchers have also developed public lectures showcasing research in off-campus locations. These “Café Scientifique” events have proven popular and have been running since 2015 in conjunction with researchers from the School of Applied School Sciences.

Contribution to the Research Base

Keynote Talks

Many staff in the unit have given external invited talks, below we list only some examples of Keynotes talks:

Hill was Keynote Speaker for the 7th International Conference on Smart City and Informatization 2017: “Realising Smart Manufacturing with the Industrial Internet of Things”;
Xu was Keynote Speaker for the 2017 International Conference on Sensing and Imaging, Chengdu, China, and Keynote Speaker for the 2016 International Workshop on Signal Processing with Applications in Scene Investigation.
Lu has given several keynotes talks including “Big data vs. Environment - a Challenge in Both Areas”, International Conference on Change, Innovation, Informatics and Disruptive Technology, 2016, London, UK; the Fourth International Conference on Advanced Communications and Computation, France, 2014.
Antoniou was Keynote Speaker at the 4th International Conference on Web Intelligence, Mining and Semantics, Thessaloniki, Greece; ONTOBRAS 2015: Brazilian Seminar on Ontologies, Sao Paulo, Brazil; IISA 2019: Information, Intelligence, Systems and Applications, Patras, Greece; PRICAI 2019: Pacifi Rim International Conference on Artificial Intelligence, Suva, Fiji; and WISE 2020: 21st International Conference on Web Information Systems Engineering, Amsterdam, Netherlands.

Editorials

Staff are or have been editors of prestigious journals in the area, with some examples below:

- **Antoniou** is on the Editorial Board of the Artificial Intelligence Journal, Knowledge and Information Systems and International Journal of Artificial Intelligence Tools; and he is Guest Editor of Artificial Intelligence in Medicine (2019-2020) and was Guest editor for International Journal of Artificial Intelligence Tools, Special Issue on Advances of AI (selection of papers from MIWAI 2015, 2014, 2013.
- **Faber** was on the Editorial Board for Journal of Artificial Intelligence Research - Editorial Board for Advances in Artificial Intelligence.
- **Lane** was Guest Editor, Special Issue of MDPI Sensors Journal (Q2 in SJR) on Industrial Internet of Things.
- **Allen** is an editor of a new journal, Journal of Emerging Trends in Computer Science and Engineering.
- **Vallati** is member of the Editorial Board of the Artificial Intelligence in Medicine Journal, and of the Journal of Creative Music Systems. Also, he was guest editor of the Fundamenta Informaticae special issue on selected papers from RCRA-18.
- **Lu** is Guest Editor for two special issues in the International Journal of Information Retrieval Research, Special Issue on Ontology and Innovation: Part 1 and Part 2. She is the founder and Editor in Chief for International Journal of Information Retrieval Research, IGI Global Ltd. USA since 2012.
- **Chen T**. is Lead Guest Editor for Artificial Intelligence in Medicine's forthcoming Special Issue on Medical Analytics for Healthcare Intelligence.

Conference Organisation and Management

Staff have acted as organisers of many conferences and workshops. Some examples are given below:

- **Antoniou** was PC Co-Chair of IEEE International Conference on Knowledge Graphs 2020, General Co-Chair of JIST 2016 and Conference Co-Chair of MIWAI 2015.
- **Faber** was General Chair of the 9th International Conference on Web Reasoning and Rule Systems (RR 2015) and Chair of the First Workshop on Trends and Applications of Answer Set Programming (TAASP 2016).
- **Hill** was General Co-Chair of The 8th IEEE International Conference on Smart City and Informatization, Guangzhou, China, 2020; and General Co-Chair 14th IEEE International Conference on Ubiquitous Computing and Communications (IUCC 2015), Liverpool, UK, October 26–28, 2015.
- **Xu** was Program Chair for 22nd IEEE International Conference on Automation and Computing (IEEE ICAC'16), and General Chair for the IEEE ICAC'17 Conference.
- **Lu** was Scientific Committee Chair of International Conference on Communication, Management and Information Technology at ICCMIT'17, Warsaw, Poland and at ICCMIT'18, Madrid, Spain.
- **Vallati** was Co-Chair of the International Symposium on Combinatorial Search (SoCS), May, 2020. He was conference co-chair of the 13th International Symposium on Combinatorial Search (SoCS 2020).
- **Parkinson** was Co-Chair of International Conference on Automated Planning and Scheduling (ICAPS) Application track at ICAPS-19 in Berkeley (CA), USA, and in Nancy, France, 2020. He has been co-chair of SPARK, the Scheduling and Planning Applications woRKshop workshop at ICAPS-17, ICAPS-18, ICAPS-19 and ICAPS-20. He

was Chair of PLANSIG workshop, University of Huddersfield (2016), and is Area Editor of EAI Endorsed Transactions on Security and Safety.

- **Qin** was Program Co-Chair, The 9th International Symposium on Internet of Ubiquitous and Pervasive Things (IUPT 2019), Leuven, Belgium, April 29 - May 2, 2019; Program Co-Chair, The 8th International Symposium on Internet of Ubiquitous and Pervasive Things (IUPT 2018). Porto, Portugal, May 8-11, 2018; and Program Co-Chair, The 7th International Symposium on Internet of Ubiquitous and Pervasive Things (IUPT 2017), Madeira, Portugal, May 16-19, 2017.

Examples of Prizes won by Saff

- **Xu** won Best Paper Award, An Innovative Crowd Segmentation Approach based on Social Force Modelling, Yu Hao, Zhijie Xu, Ying Liu, Jing Wang, Jiulun Fan, presented at ADVCOMP 2018, The Twelfth International Conference on Advanced Engineering Computing and Applications in Sciences, Athens, Greece, November 18-22, 2018. ISBN: 978-1-61208-677-4 https://www.iaria.org/conferences2018/awardsADVCOMP18/advcomp2018_a2.pdf
- **Faber** led the team (himself, and 2 PhD students) that took **first place** in the 2014 FLoC Olympics Answer Set Programming (ASP) Modelling Competition at the FLoC Olympic Games, instituted by the Federated Logic Conference, and held in the Vienna Summer of Logic, July 2014. Results page: https://www.mat.unical.it/aspcomp2014/FrontPage#liveevents
- **Hill** won Best Paper Award, A Multi-layer Security Model for 5G-enabled Industrial Internet of Things, Hussain Al-Aqrabi, Anju Johnson, Richard Hill, Phil Lane, Lu Liu, presented iSCI2019, The 7th IEEE International Conference on Smart City and Informatization, Guangzhou, China, November 12-15, 2019. ISBN: 978-981-15-1301-5. He received 'IEEE Outstanding Leadership Award' at the 14th IEEE International Conference on Ubiquitous Computing and Communications (IUCC 2015), Liverpool, UK, October 26–28, 2015.
- **Vallati** won **first** prize in the temporal track of the 2018 edition of the International Planning Competition, with a system called TemPoRaL (https://ipc2018-temporal.bitbucket.io/). He won **first** prize in the PR track of the 2nd International Competition on Computational Models of Argumentation (ICCMA), in 2017 (http://argumentationcompetition.org/2017/), with a system called ArgSemSAT.

Competition Organisation

- **Vallati** was co-organiser of the 2019 Sparkle Planning Challenge (http://ada.liacs.nl/events/sparkle-planning-19/) - an international competition of the AI Planning community aimed at assessing the complementarity of existing planning techniques.
- **McCluskey**, **Chrpa** and **Vallati** were co-organisers of the 2016 international competition ICKEPS (https://ickeps2016.wordpress.com/organisers/) with Dr T Vaquero of MIT.
- **Vallati**, **McCluskey** and **Chrpa** formed the organising team of the deterministic track of the 2014 IPC (International Planning Competition*)* (https://helios.hud.ac.uk/scommv/IPC-14/).