Institution: Manchester Metropolitan University

Unit of Assessment: B11 Computer Science and Informatics

1. Unit context and structure, research and impact strategy

Computer Science research at Manchester Metropolitan University focuses on the real-world applications of technology that are of strategic importance to the UK's economy and society. Research in artificial intelligence (AI) and cybersecurity aligns to local and national Research and Development (R&D) priorities. Leadership of collaborative initiatives such as the Greater Manchester AI Foundry and Cyber Foundry consortia give us the means to translate our research into economic and commercial impacts. Interdisciplinary research with healthcare, social science and agriculture is rapidly expanding and leading to new developments that are transforming the lives of people across the world.

The vitality and sustainability of our research and impact strategy is evidenced by:
- A 100% increase in the number of staff that we are returning to REF 2021.
- A 156% increase in research income from £1.4m in REF 2014 to £3.58m in REF 2021.
- A 113% increase in PhD completions from 16 in REF 2014 to 34 in REF 2021.
- Leadership of the £12m AI Foundry and Cyber Foundry projects.

Unit context and structure
Research is led by the Centre for Advanced Computational Science (CfACS), one of 14 flagship University Centres for Research and Knowledge Exchange (UCRKE) that were established as part of the University's ambitious RKE Strategy (see REF 5a).

CfACS is quality-focused and innovation-driven. It was created following an assessment of REF 2014 results mapped against areas of growing research excellence that link into the strategic policy landscape including the Industrial Strategy, the Science and Innovation Audit and the national skills agenda. CfACS was approved with a five-year development plan that outlines its management structures, research themes and includes specific funding, publication, citation, impact and staffing strategies.

Yonghong Peng (Professor of Artificial Intelligence) and Liangxiu Han (Professor of Computational Science) provide leadership for CfACS, which includes 54 staff (29 full research members with a significant responsibility for research, seven research assistants, seven Knowledge Exchange members who lead on industrial collaboration and ten associate members undertaking research skills development). CfACS currently has 40 PGR students.

CfACS is submitting 23 staff to B11 with a further six staff submitted to B12 Engineering. Staff in CfACS are from the Department of Computing and Maths in the Science and Engineering Faculty, one of the UK's largest providers of research-led teaching in Science and Technology.

This submission includes four research themes:

Data Science
With funding from BBSRC, Royal Society (Newton Advanced Fellowship), British Council and Innovate UK, data science research develops interdisciplinary methods, frameworks, algorithms and systems to enable the extraction of knowledge from the integrative analysis of structured and unstructured data. Our research concerns data science fundamentals and the application of cutting-edge technologies in big data, machine learning/deep learning, AI, natural language processing, governance and security. The impact of our research on social network analysis, data science and AI in Pakistan is in impact case study (reference: ICS 3).

Machine Intelligence
Machine intelligence research explores the design and application of biologically and linguistically motivated computational paradigms (e.g. conversational agents, natural language

systems, robotics and synthetic biology), computational intelligence, adaptive psychological profiling and human-computer interaction. This group is investigating the ethical, social and legal dimensions of AI through place-based research, working with policy think tanks and local and national government and community stakeholders (ICS 1). Research is funded by the European Commission and Innovate UK. This group provides academic leadership for the GM AI Foundry.

Smart Infrastructure
Smart infrastructure research focuses on the increasing demands of digital transformation and Industry 4.0. Researchers investigate future network and computation (e.g. 5G and 6G), intelligent transport, connected healthcare, Internet of Things and smart cities. Research leads to the development of tools and methodologies that address challenges in cybersecurity, privacy and computer forensics (ICS 2). Funding comes from industrial partners and Innovate UK. This group provides research leadership for the GM Cyber Foundry.

Human-Centred Computing
Research focuses on computer image and video analysis, visual computing, augmented/virtual reality, serious games and approaches to empower individuals to take better control of their data. Projects funded by The Royal Society, Cancer Research UK, EPSRC and Innovate UK are concerned with ageing and the use of virtual cosmetics. Interdisciplinary collaboration is leading to new innovations for the detection and amelioration of conditions such as dementia and diabetes, human motion analysis for rehabilitation and serious games for the development and understanding of healthcare issues.

Review of plans and objectives from REF2014

REF2014 Objective 1 - Cohesion and Communication
Our major objective in 2014 was to strengthen core areas of research and to encourage interdisciplinary activities. CfACS has provided the leadership to achieve this primary objective. We have built critical mass with a large uplift in the volume of staff and outputs, increased quality, and fostered interdisciplinary research. Research cohesion has been strengthened through significant investment and the career development of staff (Section 2).

REF2014 Objective 2 – Key themes
We have continued to collaborate with high-quality partners in the delivery of technology that is important to the wider economy and society. Research in AI, cybersecurity and big data aligns to 'future and emerging technologies' and are important themes in the Government's R&D ambitions. We have built on strengths in AI and Digital Health with industrial partners, NHS Trusts and healthcare academics. For example, the development of AI-enabled technology for the early detection of diabetic foot ulcers has led to clinical trials expected to deliver significant patient benefits and cost savings (see output reference: 2354).

REF2014 Objective 3 – Facilitation
We aimed to enhance the quality of research by securing increased levels of external funding and through additional investment in the development of staff. We have achieved increased value of competitive awards over the assessment period winning £5.27m from prestigious funders (EPSRC, STFC, BBSRC, Innovate UK, The Royal Society, Cancer Research UK, H2020). We have also captured significant knowledge exchange funding to transfer research excellence into impact through the award of ERDF funds for the AI Foundry and Cyber Foundry.

REF2014 Objective 4 – Public engagement leading to impact
We have curated innovative and popular Manchester Science Festival events characterised by a deep understanding of best practice that go well beyond 'top down' dissemination formats. In 2018, we developed an immersive theatre experience that put AI 'on trial' in the Manchester Police Museum and in 2019; we delivered an event around public attitudes to AI. The results of these activities are informing our forward strategy and the development of initiatives such as the Greater Manchester Charter for Ethical AI.

Strategy for the next ten years
Our future strategy aims to enhance research excellence, targets the delivery of global impacts, encourages the development of new areas of intellectual leadership and increases opportunities for commercial development. We will achieve this by supporting a collaborative and inclusive research culture; inspiring support for future research leaders and promoting our world-leading research.

Investing in People: We are continuously strengthening our themes by investing in high-quality staff that understand our ethos and are passionate about our mission. We will focus on expanding the equality and diversity of staff and have ambitions to create a gender-balanced research centre. We support our ECRs to become future leaders with continued mentoring and access to development programmes (Section 2). We will expand national and international collaboration linked to strengths in AI, data science, and cyber security.

Sustaining excellence: We have an important role in helping businesses to recover from Covid-19. The impact of our research on the technological advancement and productivity of SMEs and its link to the future skills agenda will be critical for Greater Manchester. We will develop a 'Research Institute for Future AI' that will support the rapid and extensive uptake of AI-enabled technology. Our work will be at the forefront of efforts to promote an ethical approach to AI, and we will embed this approach across disciplines and sectors for the achievement of positive economic and societal impacts. Postgraduate researchers are vital for the sustainability of our research, and we will embed them into the full range of our activities so they are well prepared and equipped for their future careers.

Engagement = Impact: Collaboration is vital for our intellectual and financial sustainability and is the key mechanism for delivering economic and societal impact. We anticipate that future funding will go to interdisciplinary projects that can harness the collective knowledge of diverse teams of researchers, industrial partners and communities. The sustainable partnerships that we are developing through our KTP pipeline and large-scale KE initiatives will ensure we play an important role in these emerging opportunities. We will set ambitious targets for the growth of research awards and deliver impacts with a global resonance.

Enabling impact
CfACS has an Impact and Engagement Manager who helps staff to embed impact across research activities. The Impact Manager works with a group of seven KE members whose focus is on the translation of research into activities that lead to impact.

We have an outstanding KTP portfolio supported by an award-winning team. In the assessment period we have secured £2.3m for 17 KTPs that have transformed the productivity of North West SMEs. We have delivered KTPs across all research themes, but they have played a particularly important role as pathway to impact in cybersecurity (see ICS 2). Staff who act as KTP supervisors are rewarded by a 10% workload allocation throughout the duration of their project.

Staff are supported by *MetroPolis*, the University's research-led think tank (see REF 5a). *MetroPolis* links our research into policy and provides funding for roundtable events and resources that have helped us to respond to parliamentary enquiries.

Internal funding supports impact. Prof Liangxiu Han accessed £30,000 to develop drone technology, which led to field trials to protect food crops from disease in China. Global Challenges Research Funding (GCRF) is used for impact. For example, Dr Nawaz used GCRF to support activities around gender-based violence in Pakistan (see ICS 3).

We collaborate closely with NHS Trusts on technology-enabled healthcare. For example, we are working with the Royal Wolverhampton NHS Trust on AI applications for pathology and with the Salford Royal Foundation Trust on AI for Health and Social Care.

Support for impact will continue after REF 2021. Our Impact and Engagement Manager is already working with staff to make plans for the areas where we want to develop future benefits.

Interdisciplinary research
Our research structures and strategies encourage staff from different disciplines to undertake collaborative research that would otherwise not be possible. We have a particular strength in research that is at the interface of informatics, health and agritech, and our outputs report many collaborations with healthcare providers and international partners. 30% of the outputs included in the submission are interdisciplinary.

Examples include collaboration with ecologists on early warning systems which led to co-funded work with the EPSRC (output 2347), an exploration into the decision-making processes of physiotherapists that led to a large MRC grant on neuromuscular control in children (output 2367) and research on machine learning with psychologists and media professionals. We have won £955,000 from the BBSRC, EPSRC and Innovate UK for international interdisciplinary research in precision agriculture with botanists from the Royal Botanic Gardens at Kew and the Centre for Agriculture and Bioscience International.

Open research
Our open access policy is fully compliant with REF requirements and 90% of our in-scope outputs are fully open access compliant (without exceptions). Staff have access to resources for both green and gold open access (see REF 5a). Our institutional repository currently includes 700 items associated with CfACS. Some of the most downloaded work is on traffic-management systems and interdisciplinary collaborations on micro-facial expressions, wrinkles and ageing (over 1,000 downloads). We have UKRI and institutional funding available for article processing charges as well as arrangements with various publishers such as an IEEE Deposit Account. Twenty-two outputs were made immediately available through Gold Open Access resources including impactful research on health informatics and data science.

We are fully compliant with the Concordat for Open Research Data, adhere closely to funder policies and seek to make research data accessible and useful to others. Staff share their data using the University repository (see REF 5a), and there are examples of the use of GitHub and other systems to create datasets that have a big impact. For example, in output 2354 we report the creation of the world's largest dataset for the medical imaging of diabetic foot ulcers used by over 50 institutions from 25 countries.

Research Integrity and Ethics
Researchers are aware of their responsibilities under the revised Concordat for Research Integrity. Our unit has 3 ethics leads (Prof Han, Dr Yap and Dr Kharel) who represent computer science at the Faculty Research Ethics and Governance Committee. All staff, PGRs and taught students obtain ethical approval before commencing any data collection. Ethical approval is managed through EthOS (see REF 5a). Our Research Ethics and Governance Manager provides training and guidance and has expertise in healthcare-related research.

We participate in annual audits of compliance with the institutional expectations around research ethics and governance. We are fortunate to have staff who provide academic leadership for ethics across Computer Science disciplines. In 2019, Prof Crockett co-organised a special session at the IEEE CEC on the Ethics of Computational Intelligence and in 2020, she co-chaired a panel and workshop on Ethical AI at IEEE WCCI.

2. People

Staffing strategy
Our staffing strategy is to attract high-quality researchers and to provide support to enable staff to achieve their full potential. We have invested in staff development and infrastructure. This has underpinned a large growth in critical mass and the number of staff included in our submission has increased by 100% from 11.5 FTE in REF 2014 to 23 FTE in 2021. Our recruitment policy

emphasises the importance of high-quality research, we have workload processes that incentivise and reward good performance, staff development and training initiatives that underline our commitment to the *Concordat for the Career Development of Researchers*, support for early career researchers, and clear research-based academic pathways and promotion routes.

Recruitment
We work closely with Heads of Departments and Faculty planners to recruit into areas of expertise. The Director of CfACS and our theme leads are included in recruitment processes to ensure that candidates meet our requirements for both quality and 'fit'. Beyond like-for-like replacement, recruitment is driven by our strategic plans. We have demonstrated world leadership and reputation in specific areas and are using this leverage to attract new talent. The reputation and profile of our research is evidenced by the fact that we attract high quality from an international talent pool and we regularly receive a high volume of applications from around the world. Principles of equality, diversity and inclusion are embedded throughout our recruitment processes.

A series of new appointments has underpinned a growth in critical mass in all core areas. Twelve staff were recruited during the assessment period including two professors (Profs Peng and Aspin) and five early career researchers (Cavaliere, Drikvandi, Cunningham, Moretti and Shardlow).

Our recruitment strategy in combination with staff development activities (see below) has led to a large increase in overall research capacity, as reflected in our staffing contract profile (Table 1).

Professor	Reader	Senior Lecturer	Lecturer, Research Fellow
17%	26%	48%	9%

Table 1: Staff contract level profile

All of our submitted staff are on permanent employment contracts. 22% of our staff are ECRs.

Staff development and progression
We provide time for colleagues to engage in a *minimum* of ten days professional development each year. We organise a vibrant programme of ongoing activity including seminars where staff (including ECRs and PGRs) share findings and build collaborative networks. The University is a signatory to the revised *Concordat for Career Development of Researchers* and has held the EU *HR Excellence in Research* award for eight years (see REF 5a).

Workload allocation
All staff with a significant responsibility receive a minimum of 20% of their time allocation for research and are full members of CfACS in line with our approved *Code of Practice*. Our members have access to internal funds to produce high-quality outputs. They generate research income, supervise PhDs and mentor ECRs.

Pay and career progression
Colleagues at the top of Grade 8, 9 or 10 (Lecturer, Senior Lecturer, Reader) can apply for additional increments to reward excellent research or impact activities. Professors have their pay reviewed annually to provide the flexibility to reward outstanding contributions and retain our top performers.

Promotion from Lecturer to Professor is delivered through two Academic Career Pathways: *Education, Pedagogy and Citizenship* and *Research, Knowledge Exchange, Impact, Education and Citizenship*. In the assessment period, five staff (22% of our submission) were promoted for their contribution to the production of high-quality outputs and impact. This includes promotions from Reader to Professor for Han, Crockett and Hammoudeh and from Senior Lecturer to Reader for Yap and Kharel.

Mentoring and individual research plans

Mentoring from research leaders is a key part of our culture. All ECRs are assigned a mentor who can help with their career development. Mentors provide input into the development of individual research plans, publications and grant applications. Information from individual research plans feeds into departmental professional development reviews (PDRs), ensuring that individual research supports departmental strategies and goals.

Induction

All new staff (including ECRs) undertake an induction program, providing critical knowledge on research conduct, integrity and ethics, the use of RKE Systems, health and safety, procurement and grant management. Institutional training is provided on PhD supervision, postgraduate examining and chairing assessment panels and our equality and diversity policies. All new starters have a reduced workload during their probation period, with a 25% uplift in preparation time for units taught in their first year at the University.

Our postdoctoral research associates (PDRA) and KTP associates are members of the UCRKE and engage with seminars, training, funding and other aspects of research culture. They are supported by the PDR system, are allocated mentors and are able to access internal funds to attend conferences and research networking meetings in the same way as other staff.

Early career researchers

We currently have five ECRS (22% of our overall submission) who were all appointed during the assessment cycle. ECRs are assigned a mentor and complete an individual research plan.

We have a number of internal funding schemes and training programmes to support the career development of ECRs including Research Accelerator Grants and RKE Future Leaders. The CfACS management structure includes a dedicated ECR Lead (Prof Crockett) who represents our ECRs at an institutional ECR forum. Prof Crockett organises an annual ECR Showcase to raise the profile of individuals and their research areas. We have an excellent record of supporting ECRs to achieve their full potential, and we see this as a distinctive feature of our culture. For example, Dr Yap was appointed as a lecturer in 2011 and was returned as an ECR in REF 2014. She was promoted to senior lecturer in 2014, and subsequent participation in our Future Leaders scheme helped her to develop larger funding applications such as the Royal Society Industry Fellowship that she was awarded in 2016. This activity led to promotion to Reader in 2017. Dr Yap is now benefitting from the University's Good to Great programme that is designed for advanced career development and progression.

Internal investment and support for professional development

We provide staff with access to resources to pursue their ideas and a range of internally funding opportunities for career development.

Funding for conferences and events: CfACS members including ECRs and PGRs have access to funding to attend international and national networking events and conferences, to run workshops, to invite external speakers and for knowledge exchange and public engagement activities.

*Writing Retreats***:** CfACS organises a biannual writing retreat that has provided staff at all career stages (including ECRs and PGRs) with mutual help and support in developing their personal publication strategies and outputs.

Seed funding for the development of new activities: Staff can apply for seed funding (up to £10,000) to develop RKE activities. This has been used variously to purchase equipment, to pay for the costs of visiting research partners, to access external facilities and to support activity that can leverage new funding opportunities and generate high-quality outputs or impact.

Sabbatical arrangements: Staff have access time and resources for sabbaticals that have been used to support high-quality work. For example, Prof Hammoudeh's sabbatical helped him to develop a strong collaboration with Lab-STICC CNRS, Université De Bretagne Occidentale, France, and Al-Balqa' Applied University, Jordan. This led to the creation of the [world's first simulator for smart city digital twin](#) and the production of over 10 publications. Dr Yap used a sabbatical to establish new collaborations with University of Waikato. This led to an EPSRC funding award (EP/N02700/1) and an international workshop in conjunction with MICCAI.

Research Accelerator Grants: CfACS staff have been able to access research accelerator grants (see REF 5a) to collect preliminary data for proof of the concept and feasibility. Staff have used the funds to develop capacity in software agents and big data analyses.

Global Challenges Research Funding: GCRF is used to develop overseas links with a particular emphasis on support for impact-related activities. Prof Han and Dr Nawaz have used £12,000 of GCRF to extend partnerships around crop disease and gender-based violence in China and Pakistan, respectively.

RKE Future Leaders Scheme: CfACS has five RKE Future Leaders (Yap, Latham, Dhajel, Hammoudeh and Kharel) who have benefited from this scheme. Participants are selected through a competitive application process and are given a £5,000 personal development allowance and time allocation to attend the cohort-based learning opportunity. RKE Future Leaders has helped Yap, Hammoudeh and Kharel to secure promotions during the assessment period.

Good to Great (G2G): G2G is a competitive development scheme that provides an advanced level of career development for staff who are moving towards the highest levels of academic leadership. Each G2G participant undertakes a needs analysis that informs their learning pathway. They receive internal and external mentorship and are able to access considerable funds for personal and professional development. Dr Yap received £35,000 and teaching relief that enabled her to participate in a series of funding sandpits that led to a successful award from Cancer Research UK and EPSRC.

Strategic Opportunities Funding (SOF): SOF provides strategic investment into areas of growth that align with our research ambitions. In 2018, we invested £65,000 for Prof Hammoudeh to produce a prototype system for cybersecurity in the pharmaceutical supply chain (see ICS 2), and Prof Han accessed £30,000 to extend field trials around agritech solutions for crop disease in China (output 2363).

Staff exchange mechanisms
We have funded mechanisms in place to facilitate staff exchanges including the *International Visitor* and *Research Network Fund* that staff use to develop strategic collaborations with overseas partners. Dr Nawaz used the funding for a partnership with the National Centre for Artificial Intelligence in Pakistan, and Dr Dhajel developed links with the University of Rennes around research into smart transportation.

We also have a number of visiting professorships which staff use to develop new, externally funded collaborations. For example, Prof Ana Fernández Vilas (University of Vigo) visited staff in the Machine Intelligence group in 2018. This led to the successful award of the €64,600 grant Magos (Secure sMArt Grid using Open Source Intelligence) funded by the Ministerio De Economia, Industria Y Competividad, and joint supervision of a PhD student (output 2352).

2.4 Research students

Strategy

Postgraduate Research Students (PGRs) are a vital part of our research community. Our strategy highlights the importance of PGR quality and allocates funding to provide in-depth personalised support to develop our PGRs' research skills and career development.

A proportion of our UCRKE budget is ring-fenced to support PGR activities. In the 2019 Postgraduate Research Environment Survey (PRES) we were in the top quartile for the quality of our supervision, and we have delivered 34 doctoral completions in the assessment period – a 113% increase on REF 2014.

Recruitment and funding
Eighty students have enrolled with CfACS during the assessment period, and we currently have a diverse community of 40 PGRs recruited from all over the world including China, Saudi, Malaysia, India, Iran, France and Spain. CfACS leads the advertising, recruitment and appointment process to ensure that we attract the right candidates. All PGRs are interviewed by a gender-balanced panel who have completed equality and diversity training including a mandatory module on unconscious bias. Our commitment to individual circumstances is reflected in our PGR community. Fifteen percent of our PGR students have declared a disability, 29% are female and 46% identify as Black and Minority Ethnic (BAME).

Studentships are funded from external and internal sources. We have been successful in winning competitive funding such as the Royal Society PhD Studentship for Industry Fellows in 2017 when we were awarded £86,000 for a joint studentship with Image Metrics (output 2339). We were also the first modern University to win the EPSRC Dorothy Hodgson Postgraduate Award to support research on the detection of glaucoma (output 2342). PhD student Dr Haleem was selected as a finalist under the Transforming Society category in the UK ICT pioneer competition 2015 as a result of this project. We have received full funding for studentships from Service Power and matched funding from partners such as Intellicentrics and IBM (output 2385). We are also able to access fully funded Vice-Chancellor Scholarships which are advertised on an annual basis in high-profile global campaigns.

Monitoring and support
PGRs have a minimum of two academic supervisors including a Director of Studies who supports the development of the student's research including access to training and career development opportunities. One hundred hours of annual supervision is usually divided between the supervisory team.

The *SkillsForge* system supports student progress and development (see REF 5a). *SkillsForge* generates automatic reminders about official milestones and records training and actions from supervisory meetings. An Application for Registration takes place after three months (for full-time study) and a Progression Review or Transfer of Registration takes place after 12 months full-time). All PGRs are expected to submit within four years (pro-rata for PT students).

The most recent (2019) results of the Postgraduate Research Experience Survey (PRES) evidence our strong support for PGRs. We were ranked within the top quartile for the quality of supervision in the Computer Science and Informatics category with 100% of respondents reporting that they had regular contact with supervisors that was appropriate for their needs. We have delivered 34 successful doctoral completions during the assessment period.

PGR Support and Training
All PGRs automatically become members of CfACS, which gives them access to funding, research-focused events and the opportunity to contribute to our collaborative research culture. We run a bi-weekly seminar series that integrates PGRs into our wider mission. A departmental Research Degree Co-ordinator is assigned to provide dedicated support to PGR students. CfACS has a PGR representative (Prof Crockett) who provides an opportunity for the PGR voice to be heard and understood in CfACS meetings.

We work with the University's Graduate School to provide training for PGRs (see REF 5a). CfACS hosts away days where we discuss research, career development and practical and theoretical techniques. We encourage PGR students to join professional societies to develop their academic networks, and we signpost opportunities to get involved in public engagement activities, present at conferences, and encourage PGR representation on committees. For example, 10 PhD students were involved in the 2018 and 2019 Manchester Science Festivals supporting our events on AI. PGRs in their second and third year are encouraged to act as mentors to new students. Regular teaching opportunities are available with the process de-coupled from the Director of Studies in order to provide a range of academic experience and viewpoints. PGRs have access to lockers, staff common rooms and desks, with the majority using university laptops to allow flexible working.

Dr Ryan Cunningham provides a good 'case study' of how we support PGRs and how this, in turn, feeds back into our research environment. In 2012, Ryan was awarded a fully funded PhD studentship on a collaborative project with healthcare scientists. Following a successful completion, we were able to offer a research fellowship in Healthcare Science and afterwards a lectureship in Computing. As part of his development, we have been able to provide approximately £20,000 internal funding for Dr Cunningham to attend conferences and to purchase research equipment. In 2019, Ryan's work with musculoskeletal scientists was awarded £900,000 from the Medical Research Council (output 2383).

2.5 Equality and Diversity

We have made progress in improving equality and diversity with a particular emphasis on addressing levels of gender and ethnic representation at senior roles. The equality and diversity of our submitted staff against the total eligible population is included in Table 2 below.

Protected characteristic	% of submitted staff (REF 2021)	% of staff in overall eligible population (REF 2021)
Female	**17%**	**13%**
Male	**83%**	**87%**
Declared disability	**0%**	**5%**
White	**61%**	**73%**
Total BAME	**39%**	**27%**
Black	0%	0%
Chinese	13%	7%
Asian	17%	15%
Mixed / Other	9%	5%

Table 2: Equality characteristics of staff against the total eligible population.

Our submission is more representative then the total eligible population with more women included in the return and more staff who identify as BAME. We are more representative than the sector average in terms of ethnicity (39% of staff identify as BAME whereas the average according to the latest HESA data for academic staff in relevant disciplines is 25%). Fifty percent of our professors are female and all of our research themes are led by women. Three out of four professors identify as BAME (compared with nil in REF 2014).

We have inspirational leaders of the sector's approach to equality and diversity. Prof Crockett is Chair of the IEEE Women in Computational Intelligence Committee and Chair of IEEE Task Force on Ethical and Social Implications of Computational Intelligence. In 2019, Prof Crockett was tagged as a "Woman to Watch" (IEEE Women in Engineering Magazine), and in 2020 she was shortlisted as one of the 100 most influential women in UK Technology by Computer Weekly. Dr Latham is currently the Chair of IEEE UK and Ireland Women in Engineering Committee (serving since 2012) and is a committee member of IEEE Women in Computational Intelligence.

CfACS makes a contribution to the University's equality and diversity agenda. We provided leadership for activities that underpinned the award of Athena SWAN Bronze, and Dr Latham is currently leading a team of academics, technicians and PGRs assembling an application for a departmental submission.

Flexible working arrangements
Our flexible working procedure facilitates temporary part-time working, compressed hours, job share, and career breaks, combined with a promotions scheme to ensure that colleagues are not disadvantaged by career breaks (see REF 5a). We recognise the effect that equality-related circumstances can have on an individual's ability to research or on their productivity. Following disclosure of an equality-related issue, we adjust our expectations for the production of research. ECR colleagues have reduced expectations of research outputs.

Part-time and fixed-term staff have access to the same support and progression systems as full-time staff including PDR, career development funds and opportunities. Additional training to gaining academic qualifications is made available to all.

Support for staff and research students returning from leave
We have policies in place to support staff who are returning from leave or other long-term family absence. We have a generous annual leave allowance with enhanced maternal, paternal and adoption leave in addition to unpaid parental leave if required. We make adjustments for colleagues with caring responsibilities; those with chronic disabilities; and those returning to work after a period of sickness or leave of family-related absence (see REF 5a).

The wellbeing of staff and research students
All staff have access to the Lifeworks portal for counselling, confidential advice and support for personal issues. Lifeworks is a fully integrated wellbeing platform that provides everyone access to discounts and wellbeing assistance seamlessly via website and a mobile app. Regular meetings with mentors and research theme leaders help us to identify staff that might need to be signposted to support where appropriate.

Equality and Diversity and our REF 2021 return
In the process of preparing for REF 2021, the Unit of Assessment coordination team aimed to be fair, transparent and inclusive, following the processes set out in our University's *Code of Practice*, which we have used to guide decisions around our submission. All colleagues with significant responsibility for research are included in the submission. All staff involved in unit of assessment co-ordination have completed training on 'Managing Diversity', 'Equality and Diversity Essentials' and 'Unconscious Bias and REF2021'.

All colleagues have been made aware of the processes surrounding requests for a reduction in output expectations, and adjustments in expectations have been made where appropriate. We studied EDAP's guidance closely and decided that we could manage the cumulative effect on our submission within the revised rules and therefore did not request a reduction in the number of outputs.

We have paid particular attention to ensuring that equality and diversity are embedded into the development and preparation of the submission. The Computer Science and Informatics REF2021 Coordination Group featured one male and three female colleagues. We have taken positive steps to share the attribution of outputs: 26% of the outputs are attributed to females despite the fact that there are only 17% female staff in the overall submission.

3. Income, infrastructure and facilities

3.1 Income

Strategic investment in staff including development schemes as well as excellent support from our Research Development Managers has resulted in 51 external research awards totalling £5.26m. We have also secured significant knowledge exchange awards, principally for the GM Cyber Foundry and AI Foundry projects (see below).

Research income is £3.58m (156% larger than the £1.4m we reported in REF 2014) with funding from BBSRC, EPSRC, MRC, Royal Society, European Commission, Innovate UK and industrial collaborators. There has been a sustained uplift in external income from 2013/14 (£142,000) to 2019/20 (£863,000).

The scope of our funding portfolio remains diverse with 21% from UK Research Councils (EPSRC and BBSRC are our main UKRI sources of income) and 15% from European Funders (see table 3 below). The majority of our income is from UK business, industry and government sources including a large and successful KTP portfolio comprised of 17 projects worth £2.3m.

Diversity of Income Sources

Source of Income	BEIS Research Councils	UK Charities, Open Competition & Other	UK Govt, Industry & other UK Sources	European Union	Non-EU
Percentage of Income	21%	0%	64%	15%	0%

Table 3: Diversity of Income Sources

Major competitive awards include:

"UK-China Agritech Challenge: CropDoc - Precision Crop Disease Management for Farm Productivity and Food Security" BBSRC (BB/S020969/1), £449,193 (2019).
Prof Han leads this international project in collaboration with industry and academia in UK and China. The project overall funding is £1.5m. *CropDoc* employs cutting-edge technologies such as IoT, mobile devices, big data and AI to tackle the economic devastation that potato blight causes (output 2363).

"iBorderCtrl" European Commission (ID: 700626), €4,501,877, £301,776 to Manchester Metropolitan (2016).
Prof Crockett leads our contribution to this EU-funded project with partners from Luxembourg, Greece, Spain, Hungary and Latvia. The project implements faster, more thorough border control for third-country nationals crossing European borders. This project has received a lot of media and political attention (see ICS 1), fuelling international public discourse about the ethics of AI technology.

"Populism and Civic Engagement – a fine-grained, dynamic, context-sensitive and forward-looking response to the negative impacts of populist movements (PaCE)", European Commission (107402), €2,319,719, €332,063, to Manchester Metropolitan (2019).
This is a cross disciplinary project, led by Prof Edmonds (Centre for Policy Modelling, C17) in collaboration with Prof Crockett and Dr David McLean. Project partners include organisations in Iceland, Bulgaria, Austria, Germany, Belgium, Ireland and Finland.

"Air Handlers KTP" Innovate UK (KTP 11024) £284,948 (2018)
This project led by Dr Kharel is in partnership with Air Handlers who manufacture heating and ventilation systems that are used in hospitals, schools and other public and private settings. The KTP was awarded for the development of a smart, scalable and productive manufacturing system that could expand the existing product range through the adoption of leading-edge mass customisation techniques.

"Greater Manchester Cyber Foundry" (ERDF) £6,615,951, £3,000,000 to Manchester Metropolitan (2018)

Dr Kharel and Keith Miller (KE member) lead this major collaborative project with the universities of Lancaster, Manchester and Salford to deliver targeted business support to SMEs whilst identifying projects that can harness R&D expertise to develop new products, services and capacity. The Cyber Foundry is driving economic growth and productivity through the application of cyber research and innovation (see ICS 2).

"Greater Manchester AI Foundry" (ERDF) £6,876,491, £3,000,000 to Manchester Metropolitan (2020)
Keith Miller (KE member) leads this major collaborative project with Profs Aspin and Crockett. From disease detection using deep learning to autonomous vehicle technology using computer vision – the AI Foundry, led by Manchester Metropolitan, harnesses the research across a consortium of four universities (partners are universities of Lancaster, Manchester and Salford) to unlock new products and services in Greater Manchester's businesses.

Strategy for external research income generation

Strengthen leadership for developing collaborative larger bids: Engagement with funders and priority-setting exercises led by our Research Development Manager has resulted in an increasingly strategic approach to bidding. Experienced researchers are encouraged to bid more selectively, for larger grants. Robust peer review processes, starting with formal CfACS-level support and scrutiny, enhance the quality of bids and share expertise across the staff team.

A careful pathway of mentoring and support for ECRs: We support ECRs to identify opportunities, write convincing cases for support and conduct rigorous peer review and mentoring activities. We also provide internal investment through RKE Future Leaders and Research Accelerator Grants.

Playing our part in the Industrial Strategy and future economy: We have won large awards for knowledge exchange projects that translate research in cyber security and AI into tangible benefits for the region's economy and workforce. Our research and teaching nexus provides a fantastic opportunity for us to feed research-led innovations into a new way of doing things across Greater Manchester. Our large and expanding KTP portfolio is enabling us to translate new ideas into impact that benefits North West SMEs, and we will continue to grow this activity into the future.

Using knowledge of funders more strategically: Regular bidding workshops across disciplines share specific funder knowledge. We have used this experience to work alongside our Research Development Manager to provide critical appraisal of proposals throughout. This has been a successful approach for us with BBSRC funding and with Royal Society funding in particular.

Internal investment to support external income: As reported in section 2 we use internal funding to support early-stage ideas from our staff. Schemes such as the Strategic Opportunities Fund (SOF) and Research Accelerator Grants are used with precision to pump prime activities that have been worked up into full external proposals. For example, Dr Yap has been able to use internal investment to grow her research team and to develop collaborations with Image Metrics Ltd (output 2339) and CSols Ltd into successful awards from The Royal Society (£146,381) and Innovate UK (£218,486). This has resulted in more than 30 high-quality publications.

The development of new clusters of expertise: We have invested in the development of significant new clusters of activity during the assessment period such as "Precision Agriculture". With £30,000 internal support from the SOF and GCRF, Prof Han has constructed a portfolio of precision agriculture solutions for crop health management and monitoring, soil analysis and crop site management, which has generated more than £900,000 to Manchester Metropolitan and resulted in eight high-quality research papers.

Exceptional support from the RKE Directorate: We have a strong relationship with our Research Development Manager, who attends management meetings and works with us on long-term funding strategy. We also have access to an International Research Development Manager and an experienced Delivery team (see infrastructure below).

Infrastructure

Research and Knowledge Exchange Directorate (RKE)
CfACS benefits from significant expertise in an expanded RKE Directorate. RKE includes research development and delivery, research ethics and governance, impact, business engagement, KTP support and The Graduate School (see REF 5a).

We have access to fantastic RKE Systems including Symplectic for outputs and web profiles, Worktribe for external funding applications, EthOS for research ethics, and SkillsForge for managing the PGR student journey. We also have access to SciVal for benchmarking and reporting purposes.

We have a press officer, an HR business partner, Information Systems support and expertise for the negotiation of RKE-related contracts and commercialisation activities. We receive excellent support for the management of our web and social media presence.

Technical Support
We receive support from 16 technicians organised across research-facing teams in Diagnostic, Mobile and Digital Computing (8 FTE) and Computational Facilities (8 FTE). Research Technicians manage our "core" facilities and provide hands-on expertise for research. We are a signatory to the Science Council and Gatsby Foundation's Technical Commitment.

IT Infrastructure
We have access to a £500,000 Research Data Storage facility that provides a centrally managed data storage solution. This provides a system that is highly available with performance and storage capacity to meet current and future needs (multiple petabytes).

Library Services
Research Support Librarians provide access to 349 electronic databases including CORE, Scopus, Web of Science and Science Direct, and provide guidance on appropriate publishing routes, copyright, enquiries around Open Access and Research Data Management. The Library also manages green open access through the 'e-space' repository (integrated with Symplectic) and administers funding for article processing payments for gold open access.

Specialist facilities
Research takes place in the John Dalton Tower on 8 floors of combined research space.

The *Visual Computing Lab* is equipped with six GPU machines (including one that is sponsored by Nvidia). Research on facial analysis uses high-speed cameras and a specialist machine for facial micro-expressions research. For human motion analysis, we have two types of depth sensors to measure movement.

The CfACS *IoT Lab* has a 50-device test-bed of Internet of Things (IoT) and Wireless Sensor Networks. It is also equipped with specialist kit including IoT Care (Norma, Korea), Next Generation Firewall (Palo Alto Networks, US) and Quantum Secure IoT chipset (BST, UK). We have in-house tools, including Smart City Digital Twin, RFID deployment and planning tools, an indoor-IoT simulator and smart healthcare kits.

Adaptive psychological profiling research within the Machine Intelligence theme utilises a state-of-the art *Usability Lab* to capture and analyse human behaviour utilising a wide range of technology including remote eye-tracking hardware (SMI RED 250) and the head-mounted eye tracking system (SMI) using lightweight glasses.

Access to shared facilities and "in-kind" support
A collaboration with Scan Computers enables us to use their DGX high-performance machine, and we secured Nvidia sponsorship for training in the use of deep learning algorithms. We also received an Oracle Innovation Accelerator Program Award to use their cloud infrastructure for the proof-of-concept phase of our FootSnap AI-enabled product (output 2354).

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

Support and effectiveness of collaborations, networks and partnerships
Staff collaborate with a wide range of partners in many fields; the reach of this work is evidenced by the fact that 69% of our submitted outputs are co-authored with 114 international partners.

We participate in various European consortia including iBorderCtrl with 13 partners including Leibniz University and the National Technical University of Athens, Populism and Civic Engagement (PaCE) with 8 partners including University of Helsinki and University of Salzburg, and ImageInLife with the University of Montpellier.

Internationally, we work with partners in Pakistan on AI-enabled applications including National University of Science and Technology (NUST) and the National Centre for Artificial Intelligence. We have collaborations in China where we work on agritech applications and Internet of Things technology. We have visiting professorships at Sudan University of Science and Technology and Southwest University of China (Yap).

In the UK, partnerships include the £12m GM AI and Cyber Foundry projects with Lancaster University, University of Manchester and Salford University. We are partners in the Cancer Research UK, EPSRC-funded 'Mammobot' project that is investigating breast cancer diagnosis with University of Bath, King's College London, Leeds, Edinburgh and Imperial. We are working on the early detection of skin cancer using mobile devices with The Dermatology Centre at Salford Royal Foundation Trust.

Contributions to the economy and society
Our researchers make a major contribution to the regional economy through one of the UK's largest KTP portfolios. We have been awarded 17 KTPs leading to new products and services for SMEs including Access Systems, Blueskytec, Cherry Pop Games, RAA IT, Kindus, REM UK, Service Power, Brodericks, Packaging Automation Limited and The Insights People. We even have an international KTP for a project that uses data to enhance crop yields with the University of Johannesburg. Outcomes of KTPs not featured in our impact case studies include research on quantum technology with Service Power Ltd that led to several patents and a £14m buyout from US investors in 2017.

CfACS carries out research into the development of smart transport systems. We are partners with Network Rail on an Innovate UK funded project using disruptive radar technology to create 3D visualisations of subsurface rail infrastructure that will lead to improved safety for rail passengers. We have a KE Fellowship arrangement with the Transport Systems Catapult providing ongoing advice and consultancy and stimulating innovation projects.

Research contributes to national policy. Prof Hammoudeh's research on zero trust was cited nine times in the reports of the Joint Committee on National Security Strategy and the Joint Committee on Domestic Threat of Drones. Research in quantum annealing featured as a case study in a Parliamentary Office of Science and Technology publication. Prof Crockett's work on place-based ethical AI has engaged policymakers and data scientists in round tables organised by think tank Policy Connect with the All-Party Parliamentary Group on Data Analytics.

Prof Peng has been appointed as honorary visiting professor with SRFT and the Northern Care Alliance NHS Group to advise on the development of AI for health in the region. Prof Peng is collaborating with The Royal Veterinary College and the London School of Hygiene and Tropical

Medicine to investigate the applications of AI and machine learning in combating infectious disease and Anti-Microbial Resistance (AMR). We undertake research in partnership with University Hospitals Coventry and Warwickshire NHS Trust (automation analysis of embryoscope images), Manchester University NHS Foundation Trust (body scanning and self-esteem), Lancashire Teaching Hospitals NHS Foundation Trust (diabetes) and Norfolk and Norwich Teaching Hospital (breast cancer). We also collaborate with technology providers such as Oracle, Cisco, Croda and Image Metrics on health-related contributions to wider society.

Public and end-user engagement
We gain enormous benefits from public engagement both in terms of improving the quality and direction of our research but also the opportunity that it provides for staff and PGRs to collaborate on interesting projects. We believe in meaningful two-way public engagement in which the expertise of the public is valued. For example, the outcomes of our events at Manchester Science Festival are informing the future direction for the development of a Greater Manchester charter for ethical AI. Our staff frequently work with artists and authors to develop innovative forms of public engagement. ICS01 describes our collaboration with the award-winning Manchester-based independent Comma Press who we have worked with over a number of years on popular science fiction anthologies inspired by our research. ICS01 also features Prof Crockett's collaboration with world-renowned composer Bofan Ma, whose experimental pieces have featured in performances across Europe. Whilst we are enthused by the development of new forms of collaborative public engagement, we also engage the public through more traditional routes. Staff regularly contribute to schools engagement and outreach activities, and our researchers feature regularly in the broadcast and print media and use social media channels such as The Conversation.

Contribution to the discipline

Invited/plenary lectures: Staff are invited to give many invited presentations, plenary lectures and seminars at key international conferences. A selection includes:
- 10th International Joint Conference on Computational Intelligence, Spain 2018
- 4th International Conference on Green Computing and Engineering Technology, Denmark 2018
- International Conference on Wireless Communication and Networks, US 2018
- 18th International Conferences on Ubiquitous Computing and Communications, China 2019
- IEEE European Summer School on Smart Cities, Italy, 2017
- NSF Workshop on Interdisciplinary and Collaborative Research in Cybersecurity, USA, 2019
- ACM Distinguished Lecturer Series, USA, 2020
- Role of Network Virtualization in the Future Internet, India, 2020
- IEEE International Conference on Computing, Electronics and Communication Engineering, London, 2019
- 10th International Congress on Ultra Modern Telecommunications and Control Systems, Russia, 2018

Conference Session Chairs/Organising Committee: Staff are active members of the organising committees of several major conference series. A short list includes:
- 19th IEEE International Conference on Scalable Computing and Communications, 2019
- 4th IEEE International Conference on Data Science and Systems, 2018
- 10th IEEE International Conference on Cyber, Physical and Social Computing, 2017
- 13th IEEE International Conference on Ubiquitous Intelligence and Computing, 2016
- 19th IEEE international Conference on Scalable Computing and Communications, 2019
- 3rd IEEE International Conference on Smart Data, 2017
- IEEE International Conference on Fuzzy Systems 2015 - 2020
- IEEE Women in Computational Intelligence 2014, 2016, 2018, 2020
- 10th IEEE International Conference on Big Data and Cloud Computing, 2020

- 23rd International Conference on Medical Image Computing and Computer Assisted Intervention (Diabetic Foot Ulcer Challenge) 2020
- 18th IEEE International Symposium on Parallel and Distributed Processing with Applications, 2020
- IEEE/IFIP Wireless Days Conference 2018, 2019
- IEEE 91st Vehicular Technology Conference, 2020
- IEEE International Smart Cities Conference 2015 – 2018, 2020
- 17th IEEE Consumer Communications & Networking Conference, 2020
- IEEE Globecom, 2019 – 2020
- ACM MobiCom, 2020
- IEEE International Conference on Computing, Electronics & Communication Engineering, 2020.
- International Conference on Smart Machine Intelligence and Real-Time Computing, 2020
- IEEE Wireless Communication and Networking Conference, 2020
- IEEE International Conference on E-health Networking, Applications, and Services, 2019
- International Conference on Emerging Technologies in Computing, 2019
- IEEE World Congress on Computational Intelligence 2016, 2018, 2020
- Panel of "Women in AI" at IEEE Symposium Series on Computational Intelligence, 2020
- IEEE Symposium Series on Computational Intelligence, 2020
- International Conference on Cyber Security Intelligence and Analytics, Canada, 2019

Editorships:
Staff are members of the editorial boards or guest editors of many journals (>50):
- IEEE Transactions on Artificial Intelligence
- IEEE Transactions on Fuzzy Systems
- IEEE Transactions on Emerging Topics in Computational Intelligence
- IEEE Transactions on Big Data
- IEEE Transactions on Intelligent Transportation Systems
- IEEE Transactions on Industrial Informatics
- IEEE Sensors
- IEEE Access
- IEEE Internet of Things Magazine
- IEEE Future Directions Newsletter
- IET Networks, Computer and Electrical Engineering
- Journal of Supercomputing
- Digital Communications and Networks
- Natural Computing
- Journal of Computational Science
- Journal of Healthcare Engineering
- PeerJ and PeerJ Computer Science
- Computer Communication, Elsevier
- Personal and Ubiquitous Computer, Springer
- Wireless Personal Communication, Springer
- Cluster Computing, Springer
- Multimedia Systems, Springer
- Sustainable Computing: Informatics and Systems, Elsevier
- Journal of Multimedia Tools and Applications, Springer

External advisory boards:
CfACS makes a significant contribution to a range of external advisory bodies, including:
- International Society for Computational Biology (Han)
- IEEE Special Interest Group on Big Data for Cyber Security and Privacy (Peng)
- IEEE Taskforce on Ethical and Social Implications of Computational Intelligence and Ethics (Crockett)

- Well Being Officer for Special Interest Group on Humanitarian Technology UKRI (Crockett)
- Oracle Research Industry Strategy Council (Yap)
- Transport Catapult (Djahel)
- Adviser, Prime Minister's Task Force on Science and Technology, Pakistan (Nawaz)
- IEEE Special Interest Group on Green Internet of Vehicles (Djahel)
- Chief Adviser, Visual Intelligence Research Centre, University of Electronic Science and Technology of China (Bashir)
- IEEE Women in Engineering Chair UKRI (2016-2021) (Crockett)
- Member IEEE Women in Engineering Leadership Committee (Crockett)
- IEEE World Congress on computational intelligence 2016, 2018, 2020
- Shoman Arab Researchers Award (Hammoudeh)
- Chartered Institute of Information Security (Hammoudeh)

Fellowships and Prizes:
The quality of our research is recognised through numerous awards and prizes:
- Best paper award, the 16th IEEE International Conference on Smart City, 2018
- Best paper award, the 8th IFIP International Conference on New Technologies, Mobility and Security
- ACM Distinguished Speaker (2019-2022)
- IEEE Outstanding Leadership award as a chair of ScalCom 2019
- IEEE Outstanding Leadership award as a chair of DSS-2018
- FY2021 JSPS Invitational Fellowships for Research in Japan award
- Best paper award IEEE Conference on Cognitive Machine Intelligence, 2019
- Best student paper award by Beijing Technology and Business University, China, 2019

National and international peer review:
Staff in the unit have been members of national grant award bodies including:
- EPSRC Peer Review College (Han and Hammoudeh)
- EPSRC Funding Panel – big data call and ICT prioritisation (Han)
- ESRC Funding Panel – Canada-UK Artificial Intelligence Initiative (Peng)
- The Royal Society Industry Fellowship Joint Panel (Yap)
- Horizon 2020 proposal evaluation and mid-term project reviewer (Han)
- British Council (Han and Hammoudeh)
- IEEE CIS Graduate Student Research Grants Committee (Latham)
- IEEE CIS Outstanding PhD Award Committee (Crockett)
- Cancer Research UK Expert Panel (Yap)
- Czech Science Foundation (Djahel)
- Swiss National Science Foundation (Djahel)
- The Netherlands Organisation for Scientific Research (Djahel)
- Science Foundation Ireland (Hammoudeh)