Institution: University of Sunderland

Unit of Assessment: 12 - Engineering

1. Unit context and structure, research and impact strategy

Unit of assessment 12 is situated within the School of Engineering in the Faculty of Technology. The School strives to make a positive impact on the lives and wellbeing of local and national communities. We achieve this through innovation and research in advanced manufacturing carried out at our well-equipped research institute. There are two main research themes: a) Materials Science and b) Advanced Manufacturing and Predictive Maintenance. Both have an applied focus.

Manufacturing has been the main focus of engineering research for three decades. In the North East there are 130,000 jobs directly associated with manufacturing, 14% of the regional workforce is involved in manufacturing (the highest proportion in the UK), and there are 2,700 SME manufacturing firms in the North East. Our Institute for Automotive and Manufacturing Advanced Practice (AMAP), formed in the late 1990s, adds unique value and excellence to differentiate and enhance the student experience, the Faculty of Technology, and the University. It has sustained funding for applied research, consultancy, and training for over two decades. It has been a continuous source of partnerships and research collaborations. For example, evaluation of electric vehicles use by Sunderland Council led to Sunderland's participation in CASCADE, a large 35 city project examining different methods to reduce Carbon Emissions. **Baglee** was the city expert. CASCADE led to AMAP joining new networks to develop a range of projects. This collaboration exemplifies how work with partners continuously evolves into new partnerships, opportunities, and funding, as well as creating significant impact through 2016 IET Standards Technical Briefing produced by **Knowles** (see below). Future collaboration and impact in this area will draw on research by **Karagiannidis** on high-performance lightweight composite materials reinforced with graphene and related materials. This will further contribute to the design and production of safer and more energy efficient low carbon vehicles. Future collaboration and impact in this area will also draw on research by **Naveed** on manufacturing use of additive 3D printers to reduce solid waste.

Our research into innovative techniques to support manufacturing has real world impact and provides a high-quality student experience with excellent employment opportunities. To sustain AMAP and related research, the school research strategy fully supports the career development of our research staff by creating a culture and environment that encourages creativity, innovation and collaboration with local industry. While much of our research is applied in nature, we take great care to engage with the wider academic community in our engineering discipline, ensuring that our work is published in high quality academic journals wherever possible and is also presented at national and international conferences.

Research objectives for the School of Engineering are set within a common framework for the Faculty of Technology, aligned with the University research and Innovation strategy and are as follows:

1. **Continue to deliver and develop sector-leading applied research** in Advanced Manufacturing, Predictive Maintenance and Material Science through extended interdisciplinary collaboration with strategic external partners (industrial and academic) to increase the vitality, significance, reach and relevance of the Faculty's research base.
2. **Establish a dynamic research environment** by developing and nurturing our researchers at all career stages, by recruiting more PhD students, and by encouraging dissemination of research outcomes to the widest possible audience.
3. **Build on partnerships to develop a range of funding streams** in collaboration with SMEs, public and voluntary sectors to the benefit of the regional and UK economies, and thus further develop centres of innovation, excellence and collaboration.

4. **Undertake research contributes that directly benefits our undergraduate and postgraduate programmes** through research-informed curriculum content and student research activities.

These objectives refine and develop earlier ones from 2016 and 2018, which were, in turn, based on REF2014 objectives. These were to:

- perform and deliver **high quality research into the foundations and applications of low carbon vehicles and zero emission transport** systems and thus
- **deliver novel solutions for** managing vehicle and associated systems that encourage and enable **energy efficiency**. These first two objectives have been achieved through a team-led approach, involving research by **Baglee** on predictive maintenance, research by **Mehrabi** on energy efficiency, research by **Knowles** and **Naveed** on Advanced Manufacturing (smart factory technologies, additive manufacturing, electronics and digital technologies), and research by **Karagiannidis** on Materials Science (development of polymer matrix nanocomposites such as thermosets and thermoplastics, reinforced with 2d-materials for automotive, aerospace, construction and military applications). Research in all these areas has been supported by increased investment in materials and electronic labs.
- **Increase the level of external research income** by creating and applying a rigorous internal review process, and thus submitting high quality project proposals with an improved success rate. High quality research since 2014 has been progressed with partnerships with high-profile international research centres and by ensuring that the needs of regional industry directed investments in four state of the art labs, including a smart factory, additive manufacturing, and VR/AR technologies. Research and facilities here have also supported a significant number of Knowledge Transfer Partnerships and consultancy (Section 4 below).
- **ensure that all our research explicitly informs our teaching programmes**, and to be recognised by our students as providing them with an excellent academic experience. This has been achieved through use of research facilities, research projects by undergraduates and postgraduates, and teaching and learning informed by subject awareness and current knowledge that ensures that academic programmes are research driven. Final year BEng and Masters project students are encouraged to use state of the art resources (equipment, software, materials) efficiently and effectively in innovative projects. For example, two of **Naveed**'s BEng project students have investigated the material properties of 3D printed parts developed using Ultimaker and Markforged 3D printers with polymers and composite materials. Such student research has resulted in stronger and more serviceable engineering components. For example, the students discovered that FDM fabricated Onyx components (nylon plus carbon fibre) can be reinforced with continuous strand fibres such as fibreglass, immensely increasing strength for replacement of metal tooling for aerospace, automotive and wind energy applications. This has led to a Materials Technology paper (https://doi.org/10.1080/10667857.2020.1758475) following further microstructural analysis of fracture interfaces that has provided guidance on optimisation of raster angle and infill speed. Further projects will investigate mechanical properties of Onyx in combination with different types of strand fibers such as carbon, Kevlar and High Strength High Temperature Fiberglass to enhance practical applications.

Engineering research from 2021 will continue to have a strong focus on translational research to improve productivity through novel process technologies in manufacturing, addressing three of the Local Economic Partnership's key priorities: Digital, Energy, and Advanced Manufacturing. In line with the UK Industrial Strategy's identification of Artificial Intelligence and Data as one of its grand challenges, engineering research will develop and apply new knowledge to manufacturing and productivity challenges. This directly addresses the University's goal of being recognized as the lead regional academic institution for advanced manufacturing.

In support of its *Impact Strategy*, the University has invested: in tracking software to record evidence of **impact**, training workshops have been delivered by Prof Mark Reed (Fast Track Impact), and in an Impact officer, appointed to advise staff on how to embed impact within individual research projects and applications. She has met all research active and research aspirant staff in this unit to help them to plan for research impact. A planning exercise focused on identification of beneficiaries, stakeholders and metrics that would demonstrate impact within a particular piece of research and the development of instruments such as questionnaires to quantify impact. The University provides dedicated financial support for impact work.

The first **impact case study** covers interdisciplinary research funded by a Marie Curie Fellowship. This LeaD4Value (Lean data management for maintenance value) research project combined a broad range of multidisciplinary inputs to address the problems of data-based maintenance management in the European manufacturing sector, focusing on the aspects of business value management, reliability and maintenance engineering, and data sciences. This resulted in wholescale modernisation of the asset maintenance management system for a major manufacturer (Faurecia, a tier-1 supplier to Nissan Manufacturing UK, who produce 1/3 of all cars in the UK). It underpinned the company's £50,000 investment in a Computerised Maintenance Management System (CMMS) during a period of major political and economic uncertainty. The CMMS speeds up data collection and operates across the site's entire plant and machinery asset base, which has a net book value of £3.25 million. The impact here saved several hundred hours and several £000's in manufacturing costs by increasing production hours by around 1,100 per year through reduced breakdowns.

The second **impact case study** covers applied research with the ERDF funded ongoing Sustainable Advanced Manufacturing project (SAM, now funded to 2023, total funding £10.9M). SAM works with local SMEs to improve production, quality, and manufacturing processes through innovation, creating and saving regional jobs, introducing new systems to improve quality, increase sales and enter new markets etc. **Mehrabi,** research lead for SAM, manages 3 senior research fellows. Impact here is underpinned by a broad range of previous research on design, supply chain and process, and predictive maintenance. As with much of the impact from the Faculty of Technology, SAM builds on decades of successful regional research and knowledge exchange projects, including Engineering Fellows and Digital Factory. SAM is attributed with creating 198 FTE new jobs, increasing sales turnover by £20M and Gross Value Added by £6.6m. Productivity (as Output per Hour) increased following SAM support by an average of 9.1% to £64.43 (compared to sector-level average of £40.96 at 2020 prices across the UK and £36.45 within the North East). For each £1 of funding, SAM delivered benefits of £2.34 for the regional economy.

In addition to these case studies**,** the unit's long history of effective engagement with advanced manufacturing in the North East of England reflects the University of Sunderland's standing as a significant regional anchor institution. This has enabled continuous sustainable impact, especially through Automotive and Manufacturing Advanced Practice (AMAP) within the Faculty of Technology. AMAP has maintained a leading edge on industry trends, currently focusing on support for exploiting Industry 4.0 opportunities. Direct funding from industry and from regional, national, and European sources has supported over three decades of collaborative research (AMAP and predecessors) and its application in practical contexts. This engagement spans a range of activities from contract research, collaborative projects, large scale support projects for advanced manufacturing, and bespoke training and consultancy. This broad portfolio of activities and funding supports sustainability and vitality through the engagement of post-doctoral researchers to address research challenges that are grounded in pressing manufacturing challenges. More recently, degree apprenticeships have added a new route to potential research impact, as projects are designed with input from the sponsoring employer. Final year industry-based projects have often highlighted new ideas for research collaboration between staff within engineering as the industry partner supply the degree apprenticeship. One example has arisen from Faurecia and their degree apprenticeship, where a project student has worked closely with a member of engineering

staff to develop a different metric to record training and skill developments. This project has now been developed by the engineering staff, in which the results will feed back to teaching. We have also supported our relationships with manufacturing through the appointment of visiting professorships (see Section 2).

Recent appointments are already demonstrating impact. **Karagiannidis'** work on mass production of graphene and highly conductive graphene printing inks has created an attractive low-cost replacement for more expensive materials, such as silver or organic polymers, the pillar materials in printed electronics. These new graphene inks have been made commercially available to customers via Merck and Versarien PLC. Graphene offers an eco-friendly solution compared to metal inks which give rise to water toxicity, cytotoxicity, and genotoxicity. **Mehrabi's** research has applications to the turbine blade manufacturing process and the reduction of defects, energy, and materials waste. A potential research collaboration is under discussion here.

Consultancy work is another pathway to impact. Research knowledge guided the introduction of a new maintenance system for TechnipFMC. The senior manager also registered for an MPhil, which he completed after moving to the company in the first case study. This work is an example of sustainable impact across SMEs through multiple pathways to impact. Similarly, work with Greencore on a 10-month project examined the need for a new system to collect and analyze production data and modelled new scenarios for maintenance shut down. Also, two days were spent testing the audit system at a new company, Vailent Boilers. A new maintenance and production strategy was proposed based upon the data collected. Lastly, in relation to the CASCADE work on electric vehicles, **Knowles** was a Member of Advisory Panel for Electric Vehicles Infrastructure for Fleet Operations, which published an IET Standards Technical Briefing in 2016.

A further pathway to impact has been short courses (CPD) and taster short courses, where AMAP has been key in development and delivery of research-informed courses for staff within industry on manufacturing, supply chain, maintenance and condition monitoring, product quality and engineering management. For example, **Morris** and **Baglee** delivered short courses for Hitachi Rail on production quality, asset management and supply chain management. In addition to providing case studies of manufacturing problems and solutions for engineering students, it also seeded the initial discussion for the LeaD4Value Marie Curie project. Successful AMAP work has led to securing funding for developing skills training programmes for manufacturing SMEs in Europe (Erasmus+ ICreHub) and for disseminating research through Industry 4.0 training programmes for companies in India (Royal Academy of Engineering, supported by Newton Fund).

Research in Advanced Manufacturing is inherently **interdisciplinary**, with collaborations within areas such as materials science, manufacturing management, digital technologies, data science and AI. These collaborations have always underpinned the sustainability and viability of our research by providing access to funding, data, collaborators, and practical challenges that require advanced applied interdisciplinary research. Recent collaborations have increased the interdisciplinary reach of research on Innovative Manufacturing through further consideration of supply chain research (business), creative design (new approaches to materials use), Health Sciences and related fields (e.g., pharmaceuticals, cosmetics, food and drink) and Computer Science (AI and HCI). As an example, AMAP's Framework 7 HYACINTH project investigated the use and social acceptance of hydrogen as an alternative fuel. Within this project, AMAP considered the implications of local government plans, alongside consideration of technical feasibility.

As required for an **open research environment**, the University's 2015 *open access mandate* requires all authors to deposit final peer-reviewed manuscripts, where this is permitted by the publisher, to our open access repository (SURE) within 3 months of acceptance for publication. Our strategy is to encourage authors to submit articles to Journals with Green Open Access

routes, but funding is also available to support Gold open access where this is more appropriate. Websites for funded projects also enhance the accessibility of the unit's research. We take particular care to ensure that, wherever possible, outcomes of our applied research are fully exposed to the wider engineering academic community, to the benefit of our discipline.

A key aspect of **research integrity** is for all research projects to be compliant with institutional commitments to the *Research Integrity Concordat*. There has been investment in an online ethics submission system (*epiGenesys*) to support staff through a single approval process, with access to legacy data on approvals and submissions. Ethics training is provided to all staff and research students via the university central staff development programme.

2. People

The School takes a balanced approach to staffing, with some posts focused on teaching, and others on special projects such as those within AMAP. There is no requirement for all colleagues to be research active, although all are expected to be aware of, and provide support to, the School's research activity. The Faculty is also committed to developing and promoting existing staff to provide leadership succession, and to growing new areas of research activity through external appointments. This has been further supported by appointments of visiting professors as part of the University's Visiting Professor and Fellow scheme, focusing on securing external partnerships via leading professionals who support research through their expertise, experience, and access to partner organizations. Visiting Professors have a key role in extending the unit's range of partnerships and developing 'critical mass' in line with university strategy. Experienced professionals who are not active researchers also make important contributions to partnerships for research active colleagues. Commercial and consultation activities are supported through appraisal and work loading. Overall, the University's strategic plan has provided comprehensive support for research staff development.

Since REF2014 the host Faculty for UoA 12 has seen significant changes in both staffing and structure. Our strategy has been to replace some departing research leaders through internal promotion to Professor (**Baglee**) and Associate Professor (**Mehrabi**). **Baglee** leads the overall theme of Advanced Manufacturing and Mehrabi leads a Mechanical Engineering subtheme on hybrid processes for joining materials. **Knowles** leads an Electrical and Electronic Engineering subtheme on smart power systems. Further research leads have been recruited externally. Dr Panagiotis **Karagiannidis** leads the Material Science research theme following the departure of Ahmed **Elmarakbi**, Professor of Automotive Composites in September 2018. Professor Elaheh **Ghassemieh** was the Advanced Manufacturing theme lead from 2016-18.

The profile of returned staff is thus 50% F1 (**Baglee**, **Elmarakbi** and **Timmis**), 17% IO (**Mehrabi**), and 33% J0 (**Karagiannidis, Naveed**). **Karagiannidis** and **Naveed** are ECRs (40% of active submitted staff). Active researchers are supported by the University's Visiting Professor and Fellow scheme. They are supported by three visiting professors who support research and teaching. They have expertise in research and teaching engineering programmes, especially new technologies for manufacturing, outstanding industry and academic networks, and established track records in attracting funding from Europe (Horizon 2020, etc.) and industry. Prof. Diego **Galar** (Operations and Maintenance) has supported the development of a Marie Curie proposal and a Eurostars proposal, supported submission of many research papers and conference presentations with staff in engineering, provided support to five PhD students in engineering, helped to attract two international students (from Spain and Finland), and delivered several guest lectures to staff and students. Dr Erkki **Jantunan** (Sensors and software systems for manufacturing) has supported the

development of a Eurostars and Horizon 2020 project and introduced engineering staff to many of his international contacts to help (in particular) ECRs to write papers, bids and otherwise support their research. He has also provided advice to PhD students, delivered guest lectures, and suggested topics for new undergraduate programmes. Prof. Bala **Shanmugam** is supporting the development of research partnerships in south east Asia. COVID lockdown led to the cancellation of his planned visit in 2020.

In line with the University's Research and Innovation strategy (2017), the unit supports staff through the allocation of additional research time, purchase of equipment and travel to national and international conferences through an annual *Individual Research Plan* (IRP) process, linked to yearly appraisals and staff development initiatives. IRPs are part of the university's transition to comprehensive, institution-level planning and resource allocation for research. The IRP process asks staff to: identify their yearly research goals during appraisal; link them to university objectives; and request resources (time, training, equipment, travel, PhD registration) to fulfil those goals. Since IRP inception in 2017 the unit has increased funding to research active staff to £20,250, supporting personal travel and small equipment purchases. Investment has increased year on year as research staff become familiar with the process (2017/18: £4,800; 2018/19 £5,500: 2019/2020: £14,800). This financial support has been supplemented with additional workload allocations to staff through the university's framework for academic work loading, each equating to 150 hours per year. There have been four such allocations since 2017, with the university providing £15,500 of support for staff time to the unit. In addition, five staff are being supported to study for a PhD supported by the University's *Support for Staff Undertaking Qualifications Policy*. Requests for such support are made through the annual IRP process.

Researcher development training is provided centrally, often seeding collaborations across the university. Courses include: "How to be an effective researcher" and the "Principal Investigator development programme". The university has also collaborated with Northumbria and Teesside universities to develop and pilot a HE Leadership Foundation funded programme "Leading on Research Excellence" for Readers and Professors across the region.

In addition to the IRP process and training, we support colleagues at all stages of their research careers as follows:

New colleagues are allocated a research mentor who provides one-to-one support ensuring that new colleagues have access to relevant training opportunities (e.g. grant writing workshops, training in PhD supervision). We seek to integrate new colleagues into existing research structures, for example PhD supervision teams to help them establish their own research profile. We work closely with new staff to develop their research portfolios. **Knowles** has supported **Naveed** (ERC), who will apply for promotion to associate professor in 2021-22. **Baglee** has supported **Karagiannidis**, who will apply for promotion to associate professor in 2021-22. Support here includes help with applying for university IRP funding, with finding research partners, and career development through the role of research student manager.

Existing, research aspirant, student facing **staff** are encouraged to become research aspirant and are offered mentorship support from the professoriate and waiver of fees for part-time PhD study. Six staff are currently registered for PhDs: Andy **Cook** (Digital Design Using Industry 4.0 techniques); Adrian **Morris** (Sensor Technology and energy monitoring); Walter **Ditch** (Product Design and Electrical Engineering); Helen **Scott** (VR/AR and human factors in engineering); Derek **Dixon** (Maintenance Management); and Glenn **Ridley** (novel nano-hardware for sustainable interior lighting and control)**.** Experienced professionals who are not active researchers currently make important contributions to partnerships for research active colleagues.

Staff seeking promotion with potential for a research career through high quality research are supported to develop a career path to (Associate) Professor. Colleagues pursuing merit-

based promotion to Associate Professor or Professor can access a mentor. Workshop support is offered in terms of applications developed from previous, successful, candidates. For example, the unit has run workshops on writing papers, bid writing, network development, often aimed at ECRs. These have been complemented by talks from Visiting Professors, with the head of the unit working with interested staff on what is required for promotion to Professor, and how progress towards this can be measured. Mentoring is provided for staff at all stages of research career development.

Contracts were reviewed for Professors and Associate Professors in 2019 as part of the university's ongoing strategy to better support research. To ensure these staff have the necessary time for research activity, face-to-face teaching hours are capped at no more than 10% of work-load activity. This allows senior researchers to act as academic mentors, mentioned earlier, and provide additional support to early career researchers, providing advice on research plans, bid writing and writing journal and conference papers.

Equality and Diversity issues in relation to recruitment, promotion, and research support are monitored by the Faculty Senior Management Team and Athena Swan Self-Assessment team. The Faculty recently became a signatory of the Tech Talent Charter which seeks to drive greater inclusion and diversity in the technology sector and is pursuing Athena Swan bronze level recognition with a bid being submitted in 2021. We have no individuals with protected characteristics to support to undertake research. The three females in engineering are all at different stages in their career and receive appropriate support for career progression. One third of the returned staff are female or of non-Caucasian ethnicity.

Recruitment of **doctoral students** has focused on development of home-grown talent, establishing an effective pipeline from our undergraduate and taught master's programmes to MPhil and PhD. Current PhD students in the unit's research student ambassadors programme support recruitment by presenting their work to undergraduate and taught postgraduate students. Two MSc Manufacturing Engineering students will progress to studying for a PhD on graphene nanocomposites with **Karagiannidis.** One of these is also a Sunderland Engineering BSc graduate, demonstrating how undergraduates can progress to a PhD. Another PhD student will join **Mehrabi's** group in 2021. Applications are being received from the USA.

The unit has 18 PhD students allowing us to support our best performing subject areas. Although a relatively recent appointment, **Karagiannidis** already supervises 4 PhD students, with at least two more to join his group after summer 2021. We have an ethnically diverse group of PhD students and our promotional material is sensitive to gender. We have two female doctoral students (one in maintenance management, one in VR/AR) and are dedicated to improving PhD processes to help women and diversity thrive in our engineering research. The school has a strong track record of female Masters students progressing to PhD. In addition, we promote PhD opportunities to all and ensure our message is about inclusivity and that engineering is a discipline accessible to all.

The unit's Research Student Manager **Karagiannidis** oversees end-to-end management of research students. Staff student liaison committees are held each term and the unit has a PGR representative from the student body. Once registered, doctoral students have an annual monitoring review each year from month 9 of year one. Since REF 2014 every engineering PhD or MPhil student has successfully completed their Annual Monitoring Review and submitted their thesis within time, evidencing the effectiveness of the school's implementation of University procedures.

PhD students, in collaboration with their director of studies, are required to complete a personal development plan. Training workshops such as preparing to teach are offered to all students and we provide students with the opportunity to support module delivery to gain teaching experience.

We encourage students to apply for recognition as AFHEA and have four students recognised at this level: Abdu Shaalan, Anthony Anderson, Ibifuro Ihemegbulem and Khamis Alromaimi.

The university organises Research Fridays for PGRs at Institutional level. To support PGRs, the university's Graduate Research Support Office created hubs at three campus locations as social spaces where they can also work alongside each other. Engineering PGRs benefit from the hub on St. Peter's Campus, which brings them together as a cohort, reduces feelings of isolation, promotes peer support, strengthens PGR research culture, and stimulates cross fertilisation of inter-disciplinary ideas. Post-docs and PGRS are also invited to the biennial university research conference, professorial lectures, and faculty seminars.

Subject specific training for PGR students is delivered in "Research Friday" workshops, for example **Knowles's** series on "Engineering Good Research". Generic PGR research skills development is provided through the institution's VLE with courses designed to support processes and the research degree – for example literature review processes, presentation and performance skills, ICT skills. Different workshop sessions are offered in a block teaching mode. A four-day induction programme is provided, which facilitates networking. Students can also access relevant modules on Masters programmes. The Graduate Research School provides several courses that are tailored to the students' year of study. A training repository is provided via the institutional learning environment. Our subject specialist librarian offers a research buddy programme to support research students with literature searches and additional training courses e.g. How to get published with IEEE led by Ed Wong

The University's performance in the Postgraduate Research Experience Survey (PRES) placed it 2nd out of 63 institutions in 2018 and 11th out of 103 institutions in 2019.

3. Income, infrastructure and facilities

The unit's funding strategy is directed by a hybrid revenue approach, building on partnerships to develop UK & EU funding streams. The focus is to build upon and strengthen the unit's success in research impact through co-created long-term collaborative research and partnership with industry and local, national and international government. Knowledge Transfer Partnerships (KTPs) are a strategic source of income in support of collaborative partnerships.

In alignment with the University's focus on applied research, grounded in decades of engineering research that has engaged extensively with the private, public and third sector, research income for this unit is primarily from funders of collaborative research projects, often from nationally or internationally competitive sources. These include research funded by EPSRC, EU (including Marie Curie), the Newton Fund (mobility grant, **Karagiannidis**), two KTP projects (**Knowles's** projects with Imprint and Atorus), City of Sunderland, and consultancy projects (e.g., TechnipFMC). The applied collaborative nature of much of this research results in strong pathways to impact, much of it facilitated by AMAP, which aims to inform, inspire, and innovate in Advanced Manufacturing, and achieves this by being an innovative, accessible, and outward facing provider of support for industry, based upon application of research and knowledge of Advanced Manufacturing regionally, nationally, and internationally.

University support for research and impact comes from the Research Office (within the Enterprise and Innovation Directorate) supported by the Research and Innovation Group, a committee of Academic Board. Applied research in this unit does not require use of major external research facilities in the UK or overseas, although industrial collaborations do provide access to facilities and materials (see below). Activities are supported by faculty facilities and technical staff, University support for impact activities and partnership-based grant writing, IT infrastructure and support, and the University library (for journal subscriptions, inter library loans and book purchases). In addition to this, there has been £1,392,922 of investment in the School of Engineering's to enhance research capacity through access to industry-standard technologies. This includes £526,665 invested on capital equipment in AMAP during the current REF period (£142,000 in 2015, £292,665 in 2017 and £92,000 in 2020 through the SAM project).

In line with University strategy, common use is made of infrastructure for research, collaborative outreach, and teaching. Impact has benefitted from the AMAP and SAM investments, with regional SMEs benefitting from access to resources such as VR and AR software, a two-material 3D printer, Hexagon Manufacturing Intelligence measuring equipment, and a robotic welding cell.

AMAP have invested in time and resource to ensure their staff are trained in research development, and able to support teaching and learning using the latest equipment. AMAP equipment supports undergraduate and postgraduate student projects, as well as consultancy with local and national companies. A smart factory mini production line has been recently purchased at a cost of £132K. This Industry 4.0 rig mimics a production line, supporting experiments on monitoring quality, run rate, maintenance, and other factors. This has supported collaborative design of micro-factories with SMEs, with selection of equipment as part of capital investment drawing on knowledge of the state of the art and future trends in Industry 4.0 gained within this unit through applied research. AMAP have also invested in hydraulic and pneumatic training systems (approximate cost of £20K) and specialist software (£32K) to undertake training for local industry and teaching undergraduates on campus. AMAP staff are registered for PhDs (Morris, O'Brien). An energy monitoring system (cost £5K), purchased to capture data on CNC machines for speed and energy, is used by **Morris** in his PhD research.

In addition to the AMAP investments, new facilities dedicated solely to research include mechanical, fluid, and digital manufacturing labs. Around £100K has been spent on fit out costs for these new laboratories. £20K has been spent on hardware for virtual reality (VR) and augmented reality (AR). £18K has been spent on an analytical Balance, chiller, and ancillaries.

There has also been specific investment in labs for **Karagiannidis.** A thermogravimetric analyser (~£30,000) was purchased for his research group in 2017. He also received £5,000 from the University's IRP scheme in 2019-2020 which was used to buy small equipment, labware, consumables and chemicals for his two labs, Materials formulation, and Materials Characterisation.

Naveed received £5,000 from the University's IRP scheme in 2019-2020, used to buy 3D printer materials to plan new experiments through exploration of additive manufacturing. The results of these experiments have been published, and this has supported student projects.

Mehrabi has established a metallography and heat treatment laboratory. Research here investigates the effect of process parameters on the properties of Cast, Welded, Additive Manufactured and Heat-Treated parts and components for product improvement. There is a focus on Sustainable Manufacturing, saving energy and materials with collaboration with the UK manufacturing sector. Applications areas with foundries include investment casting (ceramic shell moulds and ceramic cores). This complements earlier investments in support of **Elmarakbi's** research on high temperature polymers (state of the art twin screw extruder and injection moulding machine, £215K).

The predominance of collaborative applied research projects brings many benefits in kind, including access to collaborators' expertise, sites, and facilities, and is a primary source of the unit's visiting professors. Collaborations and partnerships have given us access to labs. and equipment at Bosch Rexroth, Siemens, Tekniker (Spain, Electronics Labs), VTT (Finland, maintenance research) and CADET (Deakin University, Australia). **Baglee's** visiting professor roles give access to experts in the USA and Sweden. Research is planned for post COVID changes to manufacturing practices.

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

Collaboration and contribution to the research base are international in nature. The unit has research collaborations within the UK, Europe, USA, and Australia. This reach is reflected in the range of contributions to the engineering research base and the sustainability of the discipline. **Naveed** collaborates with colleagues at The Open University (UK) and Northumbria University, developing research and publishing collaboratively. **Baglee** is a Visiting Professor of Operations and Maintenance at the University of Lulea, Sweden, and a Visiting Research Professor at the University of Maryland, USA. He works with research staff at both institutions on research papers and project development and has also developed an undergraduate course for Lulea.

Burn has collaborated with Prof. Ing. Mikulas Huba of the Slovak University of Technology in Bratislava on PID controller design for industrial processes and systems**. Karagiannidis** has collaborations with University of Brasilia (Brazil, Newton mobility grant funded), Chulalongkorn University (Thailand), Versarien PLC (UK), Bitrez (UK), Avanzare Innovacion Tecnologica (Spain), Instituto de Tecnologías Químicas de La Rioja, Inter-Química (Spain) and the Universities of Hertfordshire and Northumbria (UK). Seven co-authored papers with these collaborators were published in 2020.

Partners in **Elmarakbi's** EU Graphene Flagship research project (iGCAuto 604391) on advanced composite materials used in the manufacture of cars were Centro Ricerche FIAT (Italy); Fraunhofer ICT (Germany); Interquimica (Spain); Nanesa S.r.l. (Italy); and Delta-Tech S.p.A. (Italy). Waseda University and the National Institute for Materials Sciences (NIMS) in Japan also contributed to this research. **Elmarakbi** was also selected by the Advanced Propulsion Centre (APC, Warwick) as one of 17 UK exhibitors to represent the UK at the JSAE Spring Congress in Yokohama, Japan (May 2017). He was one of only ten professors worldwide invited to join the Chinese Talents-111 project on vehicle body light weighting led by Hunan University (2016-2020).

Karagiannidis has given invited talks at Edinburgh and Durham universities. **Baglee** was invited by the committee for the Australasian Association for Engineering Education to present a keynote talk in 2015 at the University of Deakin, Geelong on how to build collaborative partnerships within the UK. At the conference, he was invited to join the UK Chapter of Engineers for Australia, and the Australasian Association for Engineering Education. **Elmarakbi's** invited lectures and keynotes included 1st International Conference on Automotive Composites (ICAutoC Special Lecture, Lisbon September 2017), 2nd International Conference on Mechanics of Composites (keynote, Porto July 2016), and IMAGINENANO (invited speaker, Bilbao March 2018). He was a session chair at the joint 2017 European Graphene Forum and Smart Materials and Surfaces conferences in Paris.

Karagiannidis and **Burn** have reviewed for EPSRC**. Knowles** has been a reviewer for the Newton Fund since 2016. **Baglee** has acted as an expert reviewer for the European commission evaluating the Horizon 2020 call "Novel design and predictive maintenance technologies for increased operating life of production systems". He has since acted as a project reviewer for one funded project from January 2018, and as an expert reviewer for two Horizon 2020 project calls, LC-GV-02-2018 and LC-GV-01-2018. Within the S4Fleet project (Finnish Metals and Engineering Cluster) Baglee was an expert adviser with responsibility for reviewing key tasks and deliverables. **Elmarakbi** reviews for EPSRC and ESF and has been an Expert Reviewer for the EU's Framework 7 and Horizon 2020 programmes.

Karagiannidis is Associate Editor for the Journal of Nanomaterials, Nanoengineering and Nano systems (JNNN, SAGE Publishing) and a reviewer for Nature Communications/Springer Nature, Nanoscale and Nanoscale Advances /Royal Society of Chemistry, and Advances in Material Research, Technology/Springer, and Thermochimica Acta/Elsevier. **Naveed** has reviewed for the International Journal of Robotics and Mechatronics (Special Issues related to Advanced Machining Technologies), the Journal of Polymer Engineering & Science, and Heliyon open access journal. **Knowles** regularly reviews for engineering conferences and journals, including

Elsevier Transport Research Part B, Quality and Reliability Engineering International, Elsevier European Journal of Operational Research, Energies Journal (MDPI), International Journal of Traffic and Transportation Engineering and Journal of Cleaner Production (Elsevier). Similarly, **Burn** has reviewed for several journals, including IEEE Transactions on Automation Science and Engineering, International Journal of Electrical Engineering Education and International Journal of Mechanical Engineering Education.

Mehrabi has been a member of the Editorial Board for the Journal of Environmental Friendly Materials (JEFM) since 2017. He also reviews for the Journal of Crystals and the International Journal of Pressure Vessels and Piping. **Baglee** is Deputy Editor-in-Chief of the Engineering Asset Management Review (founded 2018) and a member of the editorial boards of: International Journal of Strategic Engineering Asset Management, Journal of Maintenance Engineering, and International Journal on Advances in Automotive Engineering (AAE). He is also a reviewer for over a dozen engineering journals. **Elmarakbi** is Founding Editor-in-Chief of the International Journal of Automotive Composites and an editorial-board member, and reviewer, of high-impact journals.

Burn has served on the Programme Committee Member of the International Conference on Informatics in Control, Automation and Robotics (ICINCO) since 2004. **Knowles** was Organiser of the 2015 Joint IET ARTS/University of Sunderland Digital Innovation Beacon Seminar on Vehicle Telematics. **Elmarakbi** is Chairman of the International Conference on Automotive Composites and has organised other international conferences such as 1st International Conference on Impact Loading of Structures and Materials (Milan 2017) and Graphene Technology-2019 in Milan. **Baglee** was the Chair of the Maintenance Performance, Management and Measurement Conference (MPMM) in 2012 at Sunderland University and has been a permanent member of the management and technical committee for subsequent conferences. He is also a permanent member on the management committee for the International Conference on Maintenance Engineering (INCOM). He has also been a committee member for the World Congress on Engineering Asset Management (WCEAM 2018, as well as an Advisory Panel member for the 30th International Congress & Exhibition on Condition Monitoring and Diagnostic Engineering Management (COMADEM 2017).

Baglee was Co-Chair and Founder of the International conference of Maintenance Performance Measurement and Management (MPMM), an Invited Panel Member of the Machine Failure Conference (MFPT 2016, USA), and a special session organiser for the 2014 and 2016 International Conferences on Data Mining. 2014 Las Vegas. USA. **Elmarakbi** is an alumnus of the Japan Society for the Promotion of Science and addressed the April 2018 Pre Departure Seminar Programme.

In the current REF period, **Baglee** has been external examiner for 16 PhDs in the UK, Norway, Sweden, Finland, India, and South Africa. **Burn** has examined two PhDs at Newcastle and one at Manchester Metropolitan University. **Knowles** has examined two Indian PhDs. **Naveed** has been External Examiner for an MPhil at Newcastle University. Further support for PhD students includes a lecture to Graphene Study by **Karagiannidis** in 2017 in Gothenburg, Sweden.

The unit has formed, developed and maintained relationships with key research users and professional beneficiaries. **Karagiannidis'** research group has been supplied with specialised raw materials from strategic collaborators: thermosetting resins from Bitrez Ltd (UK); and graphene and related materials from Versarien PLC (UK), Thomas Swan & Co. Ltd. (UK) and Avanzare (Spain). In-kind contributions of £61,400 were offered for his recent research bid.

Knowles has been Chair of the IET Northumbria Local Network since 2018. He presented to the Northumbria Branch on Vehicle Telematics – Current Challenges and Future Opportunities in 2016. **Baglee** has presented a course on condition monitoring for VTT, the Finnish National research organisation. **Elmarakbi's** work with graphene composites was extensively covered in the professional and regional press (e.g., The Engineer, Automotive Engineering, Mobility Engineering).

Baglee is founder and Chair of the North East Maintenance Forum, which promotes research, consultancy, and teaching programmes to local companies. This has proven to be highly successful in engaging with local manufacturing and engineering companies, leading to development of a UK maintenance forum, chaired by Baglee, as a collaborative partnership of several UK universities, which is supported by the Institution of Engineering and Technology (IET) through national and international dissemination activities. Baglee is a member of the Design and Productivity Executive Committee and a member of the Manufacturing Policy Steering Committee within the IET. In 2017, he became one of eight experts on the board of the International Society of Engineering Asset Management (ISEAM).

Baglee developed a successful proposal to Innovate UK to introduce advanced maintenance as a subtheme for their manufacturing calls. He is now a member of a group of academics who have been asked by UK government to address possible issues surrounding the Industrial Strategy and the sector challenge fund. He is also a member of a team that has been asked to submit written evidence to The Education Select Committee on the challenges posed and opportunities presented by the Fourth Industrial Revolution. From this, he has been asked to support a task and finish group, examining how Industry 4 themes can be developed into industry led proposals via UK research and innovation (UKRI) the seven research councils, Innovate UK and research England.

Baglee is a member of several standards organisations: British Standards Institute (BSI) AMS/001 Asset management Executive Committee; International Standards Organisation (ISO) ISOISO/TC 251/WG 3 Communication group; and ISO/TC 251/WG 7 550111 Development group. In these contexts: he has helped to design, develop new engineering asset management standards; propose a new standard for mobile electrical components; and engaged with local and national industry. Baglee is also a member of the Advanced Maintenance, Engineering, Service and Technology (A-MEST), a working group of the International Federation of Automatic Control whose membership includes both academic and industrial representatives.

The unit continues to engage with a broad range of communities and publics. Within the North East, engineering researchers are active in the IET, policy work with local government, technical support and training for regional manufacturing SMEs, and consultancy for manufacturing companies and collaborative projects with them. Support for the regional economy is a strategic priority for the University. The School of Engineering has always been a centre of excellence for such work, with longstanding support for SMEs currently provided by the ERDF funded SAM project. Both impact case studies are drawn from this long sustained large body of work. Such prioritised regional engagement results in interdisciplinary research that is not only responsive to national and international priorities and initiatives (e.g., sustainability, productivity, competitiveness, innovation) but also contributes to these initiatives through standards processes and through policy discussion and advice.