

## Unit-level environment template (REF5b)

**Institution: University of Portsmouth**

**Unit of Assessment: 10 Mathematical Sciences**

## 1 Unit context and structure, research and impact strategy

Building on our success to date, our continued focus is on producing excellent research in Applied Mathematics and Operational Research, from fundamental developments through to applications and impact motivated by societal and global challenges. We work with academic institutions, public sector bodies, and industry, to solve problems in sectors including the environment and sustainability, renewable energy generation and storage, transportation, and health. Our research output, networks and influence have grown, and our vision over the next decade is to be at the forefront of these pressing challenges while remaining rooted in excellent fundamental research.

### 1.1 Unit Context and Structure

All staff submitted to UoA10 are mathematicians from the **School of Mathematics and Physics (SMAP)** at the University of Portsmouth (UoP), formed in 2018 from the previously separate Mathematics and Physics departments. The School is part of the Faculty of Technology. The UoA has 19 staff (up from 11 in REF2014). Income, postgraduate research students and publications have grown since REF2014. There are two research groups: **Applied Mathematics** and **Logistics, Operational Research, and Analytics (LORA)**. Both groups combine fundamental research with industrial, commercial, and interdisciplinary applications.

*Table 1: Mathematics research within SMAP. Key: \*Left during assessment period.*

Logistics, Operational Research, Analytics (LORA)		Applied Mathematics	
RESEARCH AREA	STAFF	RESEARCH AREA	STAFF
Math. Programming	Li, Sim	Differential Equations and Applications	Cerasuolo, Kecker, Foster, Pickett, Lee*, Roustemoglou
Multi-Criteria Decisions	Jones, Treloar	Dynamical Systems	Simon, Burbanks, Osbaldestin
Cutting and Packing	Song	Probability, Stat. Phys.	Gnacik, Burrige
Heuristic and Meta-Heuristic Algorithms	Ouelhadj, Khosravi	Topology and Differential Geometry	Waters, Weiss

Applied Mathematics research has expanded in scope since REF2014, through increasing headcount and strategic replacing of retirees, and now covers four broad areas: (1) differential equations and applications, (2) dynamical systems, (3) interdisciplinary applications of statistical physics and probability, and (4) topology and differential geometry.

LORA has achieved substantial growth in industry partnerships and income. Its research spans (1) mathematical programming, (2) multi-criteria decision making, (3) cutting and packing, and

(4) heuristic and meta-heuristic algorithms. LORA is supported in interdisciplinary research and applications by our cross-faculty Research Centre, the **Centre for Operational Research and Logistics** (CORL, see 1.2.2, 1.2.3), jointly founded and directed by LORA.

## 1.2 Strategic Objectives: Past and Present

Past strategic aims for 2014-2021: (1) increase the quality and quantity of research, (2) develop industrial and interdisciplinary applications, (3) enable impact including setting-up a Cross-Faculty Research Centre, (4) increase and diversify our funding streams, and (5) improve numbers of PhD students and postdocs.

We now describe our achievements and plans in relation to past and present strategy.

### 1.2.1 Increase quality and quantity of research (aim 1)

To meet growing demand from external organisations in areas including renewable energy and transport, we allocated funds for the strategic appointment of new staff (Foster 2016, Lee 2015) working in industrial mathematics. This led to substantial funding success, publications and impact. We replaced retiring staff with research-active new-hires with interests that complement and broaden our Applied Mathematics research. New areas include mathematical biology (Cerasuolo 2014), applied probability and stochastic processes (Gnacik 2016, complementing Burrige), differential equations (Kecker 2014), and category theory and topology (Weiss 2016, complementing Simon and Waters). We strengthened research in LORA with new staff in optimization (Sim 2014) and computational approaches to applied problems (Khosravi 2014). Strategy and support mechanisms for developing new hires are described in 2.2.

Future goals: (a) recruit to our strengths to support existing and emerging areas and aim to improve participation from under-represented groups, (b) allocate workload and support fairly and transparently to benefit research-active staff, while improving equality and diversity, (c) identify and support fledgling research sub-groups, targeting leadership training, mentoring and support. A promising avenue, in which we are growing local expertise and collaborations, is data and machine learning that will drive new innovations and has the potential to revolutionise traditional academic disciplines.

### 1.2.2 Further develop interdisciplinary and industrial applications (aim 2)

LORA's development of industrial applications explicitly promotes interdisciplinarity. This has been particularly successful through the creation of our **Cross-Faculty Research Centre (CORL)**. LORA has also been instrumental in setting up two further collaborative networks in partnership with Catapults [<https://catapult.org.uk/>], resulting in **three interdisciplinary collaboration hubs**:

Our **Centre for Operational Research and Logistics (CORL, est. 2014)** brings together researchers working on the mathematics underpinning operational research through to those working on business applications with external partners (see 1.2.3, 3.3, 4.2).

The **South Coast Centre of Excellence in Satellite Applications (SCCoE, est. 2016)** brings together academic institutions, businesses, Catapults, and local authorities (3.3, 4.2).

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The **Intelligent Transport Cluster (ITC, est. 2018)**, combines the expertise of 54 academics from 4 different faculties and brings them together with end users (3.3, 4.2).

These clusters have enabled numerous external collaborations with businesses and local authorities, partnerships with Catapults (Renewable Energy, Connected Places, Satellite Applications), and a substantial increase in funding on collaborative projects, leading to impact (1.2.3, 1.2.4). Most recently Ouelhadj secured our role in the Solent Future Transport Zone (FTZ, £28.75m consortium) as PI (£1.8m to UoP, funded by Department for Transport) on sustainable solutions for transport of people and goods. LORA organises additional workshops and conferences with industrial practitioners (see section 3).

A key aim of the Applied Mathematics group since REF2014 was to increase applicable and interdisciplinary research. This was achieved through strategic recruitment and our Research Leads actively encouraging staff to engage with other Portsmouth academics through the five **University-wide interdisciplinary Research Themes** [see Institutional Level Environment Statement, REF5aSections2,4].

Foster's work in industrial mathematics with chemists, engineers, and the automotive industry led to impact (see 1.2.3). Appointing Cerasuolo and Gnacik further strengthened interdisciplinarity. Cerasuolo secured consortium funding to work on crop diversification and collaborates internationally on experimental and theoretical models of prostate cancer. BurrIDGE and Gnacik's work applying probability and statistical physics to social systems with Cambridge collaborators attracted media attention and led to research fellowships (sections 2 and 3). Weiss is developing applications of his Topological work to problems in machine learning.

**Future goals:** (a) further increase interdisciplinary research in Applied Mathematics, also exploring research synergies with physics; we aim to break new ground connecting mathematics with other disciplines to address global challenges in medical research, sustainability and environment, renewable energy, and data analysis, and (b) further increase knowledge transfer activities in LORA by involving a wider range of academic staff as project participants. We will increase interactions with academia and industry, stepping-up our seminar programme and number of joint proposals including cross-faculty projects facilitated by University Research Themes and cross-disciplinary hubs, to generate external contacts and impact.

### 1.2.3 Enable and facilitate impact, creating a cross-faculty Research Centre (aim 3)

We successfully delivered our REF2014 strategic aim to create a university-wide **Centre for Operational Research and Logistics (CORL)**. LORA co-founded CORL with the Faculty of Business and Law. CORL provides focus for collaboration and impact-generating activities across the University and has facilitated new industrial and academic partnerships. Its rising profile led to hosting the Annual Conference of the OR Society (OR58, 2016), with Ouelhadj invited to Chair. Its first five-year review (2014-2018) reported 100 published articles of internationally excellent quality (target 60), £3m of income (target £1.65m) from 30 projects, and 28 postgraduate research students (target 16) affiliated to the Centre, with LORA staff contributing income: Ouelhadj around £1m, Jones £652k and Song £9.6k.

Our strategy to support interdisciplinary and industry applications (1.2.2) and impact led to collaborations that enabled Ouelhadj's development of automated railway station ticket barriers

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with Cubic Transportation Systems, Transport for London, Arriva UK and the Connected Places Catapult (see **Impact Case Study**, REF3:UoA10Gatelines). In Applied Mathematics, Foster, working on mathematical models of batteries, achieved substantial funding for postdocs. His work with the automotive industry delivered “significant economic benefit” (quoting a General Motors research scientist) by reducing the development costs of battery technology and improving reliability and safety (see **Impact Case Study**, REF3:UoA10Batteries).

Further evidence of our infrastructure supporting interdisciplinarity and impact, including support from our institutional **Research & Innovation Services (RIS)** [REF5aSection4], is given in section 3.

Future goals: (a) increase impact, particularly from our Applied group; we will engage in industry open days, meetings, and host visits from industry, brokered with the help of the University Themes, RIS, and our 3 collaboration hubs; we will support staff to engage in knowledge exchange fora including Newton Gateway and V-KEMS, (b) develop existing and potential partnerships through our *MSc in Logistics & Supply Chain Management* student placement programme, and (c) continue to lead on interdisciplinary hubs via LORA and seek to develop similar initiatives for Applied Mathematics to grow business partnerships leading to impact.

#### 1.2.4 Increase volume and diversity of external research income (aim 4)

Prior to REF2014, research funding in Applied Mathematics (excluding Cosmology) was small (£101k) and mainly from one grant. We set strategic priorities to grow funding and diversify the range of sources. Our hiring plan and researcher support mechanisms to grow income are detailed in section 3.

As a measure of success, Applied Mathematics income over the current REF period is over eight times larger (£873k) than at REF2014, and derives from eight funding bodies, both academically focused (EPSRC, Royal Society, Leverhulme Trust, European Commission) and driven by commercial or industrial applications (Innovate UK, Aerogen Ltd).

LORA's success prior to REF2014, and increasing demand for its expertise, led us to identify Operational Research and Logistics as an important growth area, with impact as a priority. The cross-disciplinary hubs (CORL, SCCoE, ITC) have brought together colleagues spanning a wider range of applications, and pump-priming has helped secure roles in large grant consortia. The resulting funding now spans four areas - Renewable Energy, Transport, Healthcare, and Security and Risk - steered to align more closely with the University's Research Themes. LORA's funding has grown from £823k during 2008-2014 to £2.2m, excluding £1.8m income recently secured (Mar 2020) for the FTZ project.

Future goals: (a) increase volume and diversity of external research income by supporting all staff to make high-quality (internally peer-reviewed) applications to a wider range of sources, aiming for £1m per year by the end of the assessment period, (b) diversify staff participation in high-value bids via mentoring, and (c) expand involvement in consortia by continued “pump-priming” for exploratory meetings and seek small-scale funds to support visits and workshops.

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**1.2.5 Increase the numbers of postdocs and PhD students (aim 5)**

We have increased PhD student numbers across the unit to 19 currently (8 at REF2014), with 16 completions over the REF2021 period. We recruited 10 postdocs, with 5 currently in post, and for the first time have 2 in Applied Mathematics. Mechanisms supporting and maintaining growth are detailed in section 2.3.1.

Future goals: (a) strengthen initiatives to grow PhD numbers using faculty-wide schemes, research income and bursaries aiming for 2 per year and a 1:1 staff to student ratio, (b) develop further links with potential partners and collaborators through international students, and (c) seek cross-faculty and cross-institutional collaborations to fulfil the criteria for participation in Doctoral Training Centres. We aim to maintain excellent results in the Postgraduate Research Experience Survey (PRES).

**1.2.6 Progress on open research and integrity**

Our institutional Open Research Policy [REF5aSection3.2] goes beyond REF Open Access requirements. Timely deposit of all published outputs on the University Repository (Pure) is required, with progress monitored centrally. 98% of outputs since 2016 (whether selected or not) and 100% of submitted outputs are compliant. 100% of submitted staff have ORCIDs (cf. 43% in 2018). 83% of submitted REF outputs and 91% of all 2019-2020 outputs met the goals of the institution's Research Data Management Policy regarding publication of code and data.

Under the University's commitment to Research Integrity (informed by the Concordat to Support Research Integrity), we refer ethical considerations not addressed at proposal stage to a Faculty Ethics Committee (with 2 staff from each school). Of two projects not meeting the required standards at first review, both gained approval after modification and further review, with one requiring a third review to satisfy the Committee's rigorous standards.

**2 People****2.1 Overview**

Since REF2014, investment in new staff, success in postgraduate recruitment, and replacement of retiring staff has enabled new appointments in Applied Mathematics and LORA to strengthen activity and expand into emerging areas of interest. New PhD student admissions increased from less than one per year on average before 2017 to over two per year after 2017. Postdoc numbers have increased steadily: 10 joined over the assessment period with 6 in the last three years. New staff were supported to establish and maintain internal and external collaborations including interdisciplinary activity. "Pump-priming" funds were provided to support collaboration building and early-stage participation in grant consortia.

## 2.2 Staffing Strategy and Staff Development

### 2.2.1 Staff Recruitment

We met our REF2014 aim to recruit permanent staff in LORA (+2) and Applied Mathematics (+8), appointing research-active candidates with a track record of strong publications and potential for grant acquisition and/or impact.

Our strategy was to recruit to our strengths while looking for opportunities to complement and expand our core research areas. Appointments were targeted at developing industrial mathematics (Foster, Lee), applied probability and statistical physics research (Gnacik), mathematical biology, theoretical ecology, epidemiology, and medical applications (Cerasuolo), topological data analysis (Weiss), and analytical (Sim) and computational (Khosravi) aspects of operational research. Lee was headhunted for a Professorship but retains close links with Portsmouth through visits and joint publications.

Our strategy to help new staff realise their research potential focuses first on reduced workload and mentorship. New staff are freed from administrative roles for 1 year and given reduced teaching commitments. This enables them to make research progress, maintain remote collaborations and develop new ones, and initiate grant applications. We pair new staff with experienced mentors and prioritise them when allocating fully-funded PhD bursaries with experienced co-supervisors.

### 2.2.2 Staff Development

Staff development is nested within the University's People Strategy 2016-2020, the *Concordat to Support the Career Development of Researchers* (CSCDR) and central HR policies [REF5aSection3].

#### Mentoring & Training including for Early-Career Researchers

Treloar, Foster, Gnacik and Cerasuolo began independent research in 2014-2020. Treloar was mentored to restart his research, leading to publication. Foster was supported by targeted PhD bursaries, reduced workload and early mentorship from Lee. His Fellowship application was supported by the University's *Themes Research and Innovation Fund* (TRIF) and the *Research Innovation and Development Fund* (RIDF). Under BurrIDGE's mentorship, Gnacik achieved research independence and promotion to Senior Lecturer. Gnacik and Cerasuolo were supported by bursaries and matched travel funding to develop collaborations.

A representative of *Early-Career Researchers* (ECRs) attends faculty research management meetings. ECRs gain peer support and representation through the institution's Researchers Forum; the Research Staff Network represents postdocs' interests.

We pair ECRs (as 2nd or 3rd supervisors) with experienced staff on PhD supervision teams to gain experience, increasing the future pool of 1st supervisors. This provides mentorship and opportunities for interdisciplinary work by including co-supervisors from outside the School.

Induction Conferences and institutional RIS Development Programmes are available to all staff and postdocs, with 13 staff attending 17 programmes during 2014-2019, including *Writing*



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*Targeted Research Proposals, Research Data Management, Becoming Reader and Professor, Fellowship Applications, Impact and Engagement, and Media Promotion.*

Stimulating exchanges with academic peers and industry

Regular research seminars in LORA and Applied Mathematics welcome national, international and internal speakers with gender balance monitored. We aim to develop additional seminar programmes with increased external participation including visits by eminent academics.

We support visiting academics and host Visiting Industry Fellows (including internationals) as part of our global engagement strategy, providing office space, computing, and integration into departmental activities. The Annual Conference of the Operational Research Society (OR58) was held in the School. The School hosted a Collaboration Manager from the RIS Business Engagement Team to enable more direct support for initiating and strengthening collaborations.

Support with fellowships, internal funding and sabbaticals

We identify and support fellowship applicants at early and established career stages. Calls are disseminated and applications reviewed by senior staff. Selected applicants are supported via constructive feedback and a cohort training programme to engage in a University bid process, most recently Foster for a UKRI Future Leaders Fellowship. The School and Faculty commit to support successful applicants by appointment of postdocs, PhD students and teaching relief. Faculty and University support is facilitated by the Deputy Director of RIS and approved by the Pro Vice-Chancellor for Research and Innovation. Recent success includes BurrIDGE for a Leverhulme Trust Fellowship and Royal Society APEX Award.

All staff are encouraged and supported to seek competitive Faculty funding for postdocs, PhD students and sabbaticals. The University devolves REF2014 QR monies to faculties that generated them, helping enable a rolling programme of bursaries.

The University Research Themes [REF5aSection3.2] strengthen focus, foster collaborations and provide financial support. The *Future and Emerging Technologies* Theme supported the successful cross-faculty Intelligent Transport Cluster with Ouelhadj as Director (£5k).

A Strategic Fellowship from the *Themes Research and Innovation Fund* supported Foster (£7.4k). The RIS *Research Development Fund* supports innovative proposals (e.g., BurrIDGE received £17k). The Faculty monitors achievement on sabbaticals, providing constructive feedback. Sabbaticals for BurrIDGE and Waters (2017) led to outputs, funding, media coverage, impact activity, and collaborations.

Development, reward and promotion

All staff and postdocs have annual *Performance and Development Reviews* to review progress, set goals and assess development needs and career plans. Discussion of career plans forms part of postdocs' regular supervision meetings in line with the Concordat (CSCDR) [REF5aSection2]. Staff development funds cover research visits, meetings, conferences and short-stay visitors (staff also seek external match funding).

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The School recognises research leadership by rewarding staff who consistently exceed benchmarks by encouraging them to apply for promotion. Research time forms part of the School's workload model. The University provides leadership training and has been quick to recognise contributions of staff through promotions, with 8 from Lecturer to Senior Lecturer, 3 from Senior Lecturer to Principal Lecturer, Ouelhadj to Reader in 2015 and Professor in 2017, Burrige to Reader in 2019, and Foster to Reader in 2020.

## 2.3 Research students

### 2.3.1 PhD and postdoctoral recruitment

Increasing our quality and quantity of research has attracted more high-quality PhD applicants. In 2020, there were 19 PhD students, with 16 completions during 2014-2020, compared to 8 students and 6 completions at REF2014. Strategic pairing of new staff with experienced supervisors and targeted PhD bursaries has built a larger pool of first supervisors.

*Table 2: Postgraduate recruitment and completion.*

PhD Student/Postdoc	2014	2015	2016	2017	2018	2019	2020	TOTAL
New PhD students	-	1	1	2	3	2	2	11
PhD completions	1	2	1	2	6	3	1	16
Postdocs starting*	2	0	2	0	4	1	*1	10

*\*Not including 6 new postdocs for the FTZ project (won March 2020) secured for 2020/21 (See section 1.2.2)*

The pipeline of future PhD students is developed by a range of activities. Talent is nurtured through Summer projects supported by small external grants, e.g., from the *London Mathematical Society* (LMS). These can lead to genuine research contribution and publications, boosting students' enthusiasm and confidence and increasing their academic employability. Undergraduate modules and projects embed research thinking and students are invited to selected seminars. We launched (2017) a new 4-year MMath degree and MRes programme.

We seek high-quality applicants and receive international applications, particularly in LORA. A rigorous interview (with a gender-balanced panel where possible) emphasises quality. All staff involved in recruitment are trained in *Best Practice in Selection and Admission of Postgraduate Students*. Supervisor training includes *Best Practice in Supervision*, *Being a 2nd or 3rd Supervisor*, *Supervising Part-Time Students*, *Managing and Monitoring Projects*, and conducting external and internal vivas.

We explicitly encourage staff to collaborate on cross-school and cross-faculty project proposals for internal bursaries. Recent examples include a joint PhD with our School of Civil Engineering and Surveying on failure mechanisms for multi-layer materials. Proposals must address training and support to be provided. We provide feedback and share best practice to develop staff ability to scope support requirements for projects.

The PhD cohort is funded by a combination of individual grants, bursaries, industry partnerships and self-funding. The Unit won nine internally funded competitive bursaries: 7 in Applied



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Mathematics (3 female, 4 male) and 2 in LORA (1 female, 1 male). These often benefit our best home-grown undergraduates.

During 2014-2020 we recruited 10 postdocs with 11 in post during the REF period (6 male, 5 female). We currently have 5 in post (4 female). Historically, these were funded by industry partnerships through LORA. We broadened this, securing two postdocs for Applied Mathematics working with Foster and Cerasuolo. The FTZ project alone will bring 6 new postdocs in 2020/21.

### 2.3.2 Induction, Support, and Progress

PhD students work in a large, shared office with access to dedicated space for workshops, mock and actual PhD vivas and meetings. New postgraduates receive induction, department training on mathematical techniques and software, and external training, e.g. from NATCOR (for LORA) and summer schools (for Applied Mathematics). The University **Graduate School** [REF5aSection3(2.2)] runs a Development Programme including research design, doctoral process, publishing, and careers. Our staff contribute specialist sessions, including on LaTeX and Machine Learning. Students are encouraged to engage in our institutional GPROF programme to gain accreditation for delivering seminars and lectures.

All students meet at least one supervisor weekly. We encourage students to submit a summary of progress and agreed goals using the Skills Forge system provided by the Graduate School. Students have annual reviews with independent reviewers that are also used to explore career plans and identify support. In preparation, students practise mini-seminars informally as a group and present them to staff for feedback.

To immerse postgraduates, ECRs and other new staff in our research culture, we run regular meetings and weekly seminars. Students and postdocs are expected to present within their group's seminars and externally. Regular large workshops and conferences are run by CORL, which funds additional travel and collaboration.

Students and postdocs must present a poster or seminar at annual Faculty Research Days, which provide cross-disciplinary networking for students, postdocs and staff, and further prepare postgraduates to present externally. Bursary funding includes costs for conferences and equipment, augmented by School provision.

### 2.3.3 Skills development and preparation for careers

The School gained the highest results across the University in the PRES in 2018, with a 100% satisfaction rating. Burridge was awarded Faculty Outstanding Supervisor of the Year.

We want our students to become independent researchers, rather than merely to complete and defend a thesis. Career aspirations are discussed in regular supervision meetings of students and postdocs, emphasising transferable and academic skills. Successes include a student who is now a postdoc in the Business School, another whose PhD was funded under an initiative to revitalise Iraqi universities and is now a lecturer at Basrah University, one is now a junior data scientist, one works for BAE Systems in defence research, and one is a lecturer in Saudi Arabia.

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Over 70% of students whose work led to publications are BAME. We aim to further increase publication rates among students.

## 2.4 Equality, Diversity and Inclusion

We have made progress towards improving inclusion in a field that is traditionally male dominated: 32% of our REF submitted staff are female (27% in REF2014). Among eligible staff, 42% are female. The gender pay gap shows median female pay 4% lower and mean female pay 6% lower in 2020. We are committed to closing this gap. The School has an internationally diverse staff from 13 countries (31% British, 27% EU, 42% Non-EU International). All permanent eligible staff members were submitted to this REF.

To ensure no significant differences in E&D were introduced in preparing the REF submission, outputs were reviewed by gender-balanced groups and approved by a panel trained in E&D. Under the University Code of Practice [REF5aSection3(3.1)], no staff members are expected to contribute specific numbers of outputs, regardless of characteristics, although E&D is considered during selection if a quality tie-break occurs. Of staff submitted, 22% are BAME (29% of eligible staff are BAME). An Equality Impact Assessment (EIA) revealed that 23% of submitted outputs were attributed to female staff and 25% to BAME. The differences in gender and BAME profiles between submissible and eligible staff result from postdocs who do not meet institutional criteria for research independence. The numbers do reflect our success in attracting BAME and female postdocs (nationally only 15% are BAME) and our commitment to building a pipeline of future independent researchers with diverse backgrounds.

All staff undertake mandatory training including *Bullying & Harassment*, *Unconscious Bias*, and *Equality & Diversity*. Staff involved in preparing this REF submission had additional training related to our Code of Practice.

The University retained its Athena Swan Bronze Award in 2018. The Department of Mathematics received the Bronze Award in 2016. We identified and achieved key aims including the creation of an E&D committee with diverse representation, more women in senior roles, rescheduling activities within core hours, recruitment materials that emphasise diversity and flexibility, and additional funding for programmes such as Aurora [REF5aSection3(2.1)]. E&D is now integrated into the agendas of all School committees. We encouraged male staff to do outreach, to balance the higher staff time previously invested by female staff. We will seek a renewed Award for the newly constituted School of Mathematics and Physics.

The School supports the LMS *Good Practice Scheme* and Institute of Physics *Project Juno*. We aim to support a *Women in OR and Analytics Network* (WORAN, Ouelhadj is on the Steering Committee). Osbaldestin, as Chair of the *Heads of Departments of Mathematical Sciences* (HoDoMs), helped develop the “Advancing Women in Mathematics” report commissioned by the LMS and launched at the House of Commons.

We ensure all staff are aware of their rights to flexible working. No staff are currently part-time or have declared disabilities, but several worked flexibly in 2014-2020. We supported staff dealing with and returning from long-term illness and with caring responsibilities with adjustments to duties, via relevant HR and Occupational Health policies, including compassionate leave and processes for timetable adjustment. To support home working in 2020 we provided students and

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staff (including professional staff) with IT, including tablets for handwriting mathematics, and a local “Keeping-in-touch” programme of weekly contact emphasising wellbeing. Postgraduates are supported by the Student Wellbeing Service.

Departmental, faculty and institutional meetings are scheduled carefully to avoid unfairly disadvantaging anyone. Staff submit requests for timetable constraints to a central team who consider E&D. We have pursued increased cross-gender and cross-characteristic representation on interview panels and committees while aiming to minimise additional burden for staff with protected characteristics. Several institutional staff networks provide peer support covering protected characteristics (e.g., Parents and Carers Network) augmented by a confidential 24-hour Employee Assistance Programme [REF5aSection3]. Additionally, CORL’s new 5-year plan includes three diversity goals: to ensure all members can (1) participate in an externally funded project, (2) co-supervise a PhD, and (3) contribute to research likely to produce high quality outputs. Progress is monitored by the Director (Jones) with senior academics.

### **3 Income, infrastructure and facilities**

#### **3.1 Value of funding secured**

We have delivered on our aim to increase the volume and diversity of external income by improving support for staff to make high-quality applications to a broader variety of sources (see also 1.2.4). LORA has been the most successful, having extensive involvement in consortia with international and UK business and the public sector. The Applied group has secured competitive fellowships and individual awards.

The University's Research Information Database (Pure) shows total awards to UoP (2014-2020 by award date) of new grants or partnerships secured involving staff in the UoA as £3.122m, with £2.325m having UoA staff as PI and £0.797m as Co-I, of which portions are received by the UoA. Income received within the REF period allocated to the UoA [REF4] was £1.655m (compared with £0.327m at REF2014).

#### **3.2 Infrastructure and strategy supporting income generation**

Our hiring plan focused on recruiting research-active individuals (and/or those with the potential for independent research) with an emphasis on industrial and interdisciplinary applications. New hires were supported to achieve their potential and we provided mentoring in an open and collaborative research environment. Alongside guaranteed funding for conferences and visits, staff were successfully encouraged to apply for University-wide pump-priming funds. This helped build external networks and collaborations and support larger grant applications by funding short-term focused sabbaticals, travel, and workshops.

Early and mid-career staff were mentored to seek internal funding for sabbaticals and “pump-priming” activities for collaborations and travel, small external grants (including for working-in-pairs), participation in consortia as Principal Investigator (PI) or co-Investigator (Co-I), or individual fellowships. Many funding calls are collected by Faculty and disseminated to the School where suitable applicants are identified by group leads and the Associate Head Research, and staff are encouraged to look for suitable opportunities.

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Staff are supported from the moment they express an intention to apply (by completing an electronic form). This triggers the review of outline proposals by School and Faculty, providing initial feedback. For those which progress, seven RIS Grants and Development Officers support drafting and costing with finance officers. Best practice is shared within the School by individuals with a track record of success who offer additional editorial, costing and personnel advice. The University Peer-Review College provides further feedback and ensures quality [REF5aSection4]. “Grant Hothouse” workshops provide mock proposal reviews. Faculty administration collects and manages bid information from intention through to post-award.

The **University Themes** and our **collaboration hubs** provide targeted support for income generation (3.3, below).

Of the staff who generated income in excess of £100k during the assessment period, 50% are female. The School recognises and appreciates all contributions. Successes have been reflected in targeted support and in promotions. A diversity goal of CORL’s new 5-year plan (2019-2023) is to ensure all researchers can participate in an externally funded project.

#### Funding of individuals including competitive and prestigious awards

Successes include an EPSRC New Investigator Grant for Foster’s work on lithium-ion batteries (£310k, 4.2.2 and REF3:UoA10Batteries), a Royal Society APEX Award (£61k) and Leverhulme Trust Fellowship (£46k) for Burrige’s interdisciplinary work at the interface of mathematics and social sciences. All were supported by School co-funding to enable teaching relief. Song received Royal Society funding (£9.6k) for a project on resilient blood supply chain system design for disaster relief, which was supported through co-funding visits.

### **3.3 Infrastructure supporting consortia, industry partnerships, and impact**

#### **3.3.1 Pump-priming**

We recognise the importance of meetings that can lead to collaboration and, ultimately, national and international funding consortia and industry partnerships. We support staff to engage early, knowing that outcomes are uncertain but that investment is necessary to ensure we play a pivotal role. We help staff build collaborations, cost projects, and plan staffing cover. RIS and the Themes help identify expertise and bring together optimal cross-disciplinary bid teams.

We described in REF2014 how pump-priming led to an EU project (“2OM”: Offshore Operations and Maintenance Mutualisation) and to LEANWIND (Consortium €15m, European Commission) that pursues cost reduction across the offshore wind farm life-cycle. LORA built on this experience, accessing mainstream EU funding, supported by our pump-priming initiatives.

We funded Ouelhadj to attend an EU 2-Seas Interreg brokerage event leading to the SLIC (consortium €4m; UoP £192k) and NEREUS (consortium €7m; UoP £223k) projects. SLIC is developing energy savings, efficiency and renewable energy use in public lighting, to increase uptake and reduce carbon emissions. NEREUS will transform wastewater into a valuable reusable source of water, nutrients and energy. We funded Jones for two visits to Norway, producing a collaboration with Arctic and North Atlantic Coastguards on ARCSAR (EU consortium €4m) to support frontline security and an Emergency Preparedness Network.

### 3.3.2 Consortium and partnership formation

Sustained activity since 2014 and the need to diversify beyond EU sources led us to bolster our infrastructure. We created a network around a core team from LORA and the University, experienced in developing consortia and industry partnerships, to respond to new opportunities and mentor staff (by pairing on projects). Successes include the recent FTZ project (1.2.2), Intelligent Gatelines (funded by Rail Safety Standards Board; consortium £1.3m; UoP £241k), and WASP (Innovate UK; consortium £900k; UoP £153k). WASP will design an integrated autonomous vessel delivery system for offshore wind farm maintenance.

In Applied Mathematics, an example instigated through pump-priming, pairing and mentoring, is Cerasuolo as PI on the European Commission funded project *Diverfarming* on Crop Diversification and Low-Input farming (£165k), which recently produced high-quality output.

### 3.3.3 Identifying and supporting impact

We foster early impact through a variety of channels. We supervise sponsored international PhD and MSc students on placements with industrial partners, brokered with the aid of RIS. We liaise with RIS and our Press Office to publicise our expertise and initiate external relationships, culminating in regular visits to non-academic partners for whom we run Continuing Professional Development courses. We host long-stay visiting academics and Industry Research Fellows from existing and prospective partners.

We train and support our researchers in identifying, understanding and achieving impact, with help from a Faculty Impact Team and the central RIS Impact Team and Collaboration Managers [REF5aSection4]. Our pump-priming funds for staff travel to exploratory meetings and international project preparation events lead to engagements with local companies and public-sector bodies and with large networks of partners. Knowledge transfer is additionally supported by internal funding schemes for innovative proposals and via external KTPs (e.g. Innovate UK).

Supporting infrastructure is enhanced by the **University Themes**, **RIS**, and our **three interdisciplinary hubs (CORL, SCCoE, ITC)**:

Our **cross-faculty Centre for Operational Research and Logistics (CORL)** brings together interdisciplinary teams of researchers from across the University (in mathematics, technology, business and industrial research) with partners in the public and private sectors, to address their challenges in areas including technology, efficiency and sustainability.

The **South Coast Centre of Excellence (SCCoE) in Satellite Applications** is supported by a consortium of 20 academic, industrial, government and third-sector partners to address challenges spanning healthcare, media, education, construction, environmental resource management, tourism, and agriculture. It helps businesses to gain a foothold in satellite applications by supporting them to develop collaborative projects, share expertise, identify and gain funding, and network with academia. It gained funding for its second phase (2019-2022) from the UK Space Agency and the Satellite Applications Catapult (total £600k, UoP £300k).

The **Intelligent Transport Cluster (ITC)** builds on 10 years of collaboration with the Connected Places Catapult (and its precursors). It unites users with academics (54 across 4 faculties of the



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University) to address goals of the Industrial Strategy and Future of Mobility Grand Challenge in land, air and marine transport. It aims to meet the market need in the South Coast region, home to the UK's largest marine and maritime sectors. The Solent area alone generates 10% of the sector's UK GDP, provides 48,000 jobs locally and supports over 3,000 businesses.

### 3.3.4 Infrastructure Leadership

Staff in our LORA research group comprise 50% of the management of CORL (Jones: Director, Ouelhadj: Director of Innovation & Enterprise, Song: Scientific Research Coordinator), 50% of the management of SCCoE (Ouelhadj: Director of Operations), and 100% of the management of ITC (Ouelhadj: Director).

These hubs and the University Themes provide administrative and financial support for networking, planning, and collaboration. CORL's first 5-year report (2014-2018) noted £3m income (target £1.65m) generated from 30 projects. SCCoE (2016-2020) established outstanding business and local authority collaborations generating income around £18m. The ITC launch event (2019) gained support from the *Future and Emerging Technologies* Theme, attracting 145 delegates (with 80 from transport businesses and local authorities).

### 3.4 Additional infrastructure including computing facilities

Academic staff, postdocs, and students are housed in the Lion Gate Building of the University's City Campus adjacent to several collaborating departments. Academics have individual or shared offices and a staff room (with kitchen) that helps encourage informal discussions. Postdocs have shared rooms and students have a large, shared office with a library area. The University Library and central administration are within walking distance, enabling face-to-face discussions with RIS, marketing, and other functions that support impact.

All staff receive desktop and laptop computers with central and local IT support. We provide licenses for specialist software including Mathematica, Maple and MATLAB.

Staff and PhD students can access the SCIAMA 1000+ cores distributed-memory High-Performance Computing cluster (at the University's Institute for Cosmology and Gravitation), via dedicated client software with support from a supercomputing technician, enabling large-scale parallel computations.

During 2014-2020 we employed additional professional staff: one to develop the CORL website, to improve its external face, with *Higher Education Innovation Fund* (HEIF) funding, and one to support bid writing.

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

### 4.1 Overview

Collaborations with national and international academic partners, industry, and non-commercial organisations have risen substantially over 2014-2020. Our research has reached its target



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audiences, including commercial end-users, mathematicians, other disciplines, and the public, disseminated through industrial links, research visits, outreach and the media.

## 4.2 Research collaborations, networks and partnerships

### 4.2.1 Collaborations within academia

Collaborations are supported by funding short-term research visits from external collaborators, often combined with seminars, by flexible funding for travel and conference fees accounting for individual circumstances, and via our research centre and clusters supported centrally by RIS and the University Research Themes. We supported applications for exchange grants to foster new partnerships. Alongside University pump-priming funds, this initiated fledgling collaborations that led to new and interdisciplinary research directions and outputs.

LORA members have formed academic partnerships in the USA, China, Brazil and Iraq: CORL funded Sim to visit Georgia's Institute of Technology to work with a world-leading team on mathematical programming, leading to high quality publications. Supervising a PhD student (now lecturer at Basrah University) under a scheme to rebuild Iraqi academic expertise yielded ongoing collaboration. We developed links with Brazilian (multi-objective optimization and biomathematics) and Spanish (Heuristics, transportation algorithms) universities. The latter was supported by research exchange visits with staff from Oberta De Catalunya University (2014) and the Public University of Navarra (2017) funded by ERASMUS.

Incoming and outgoing visits by staff, funded by the Newton Scheme, ERASMUS and international funding councils led to many good quality publications. Extended visits and visiting research students have also helped build academic partnerships in China: Li was supported by CORL and the National Natural Science Foundation of China (NSFC) to build collaborations with Shanghai University of Finance and Economics. Song was supported by the Royal Society to visit Shanghai Jiao Tong University (2019). Our School supported and hosted reciprocal visits for the project, leading to strengthened Chinese collaborations. This created new research avenues to develop a resilient blood supply chain after earthquakes, leading to several publications, invitations to speak, and contribution to a review article. The work gained the attention of NHS Blood and Transport (NHSBT). Further funding from MRC is being sought.

The School hosted Summer internships (May-August, 2013-2018) from City University, Hong Kong. We also attracted researchers supported by national and international scholarships including Villa (Della Riccia fellowship 2014) and Barbosa (UNESP, Brazil, 2018).

These initiatives strengthened interdisciplinarity in the Applied group, exemplified by Cerasuolo's recent collaboration with Consiglio Nazionale Delle Ricerche (Italy) for a project funded by GW Research Ltd (Cambridge) on the TRAMP model for prostate cancer. We provided travel funding, which included tickets for Cerasuolo's dependents. An LMS *Research in Pairs* scheme supported work on plant pathogens with Naples University. She was also external collaborator and mentor of the lead applicant on the Newton International Fellowships 2018 for Cappelli, Chiara Natural History Museum project "Choosy fungi", and has local collaborations with colleagues in Health Science and Marine Biology, one supported by a joint Masters Research

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student developing a tuberculosis model accounting for human behaviour and another modelling the influence of climate change on algal growth.

Other interdisciplinary collaborations include BurrIDGE's work with quantitative linguists from Cambridge and Pennsylvania on spatial models of language evolution. Internal support led to two competitive fellowships (Royal Society 2018, Leverhulme Trust 2016) producing multiple articles in high-quality journals, media coverage and invited lectures. Internal funding enabled outreach talks to schools, participation in a city-wide project on local dialect, and statistical support to Bristol and Portsmouth doctors for COVID-19 aerosol "cough" experiments. BurrIDGE and Gnacik adapted linguistics models in early 2020 to understand social distancing behaviour.

The School and the Czech Science Foundation (GAČR) jointly funded research visits for Gnacik (2016-present) to form collaborations with the Czech Academy of Sciences Department of Abstract Analysis. The new results on doubly stochastic matrices have led to seminar invitations at Oxford University and to the 23rd Conference of the International Linear Algebra Society in Galway. Recent funding (May 2020) from a University Impact Accelerator Account (funded by STFC) provided a postdoc to analyse social distancing using satellite images.

#### 4.2.2 Collaborations outside academia

Collaborations outside academia have been driven mainly by LORA, both directly and via our 3 collaboration hubs (CORL, SCCoE, ITC). The main non-academic user groups span public-sector organisations and authorities, and commercial organisations in transportation, healthcare, and renewable energy (including multinationals, especially in port and maritime logistics, freight and passenger transport, and offshore wind). They face challenges of managing complex flows of resources amid conflicting objectives, performance targets, and constraints. They look to LORA for techniques to help analyse the complex inter-dependencies of their business. Our researchers work directly with users to build bespoke models employing optimisation, prediction and simulation modelling, heuristics and meta-heuristic methods, and multi-criteria decision making, enabling them to plan and optimise robust operations across potential scenarios. Work with these groups, alongside contributions from Applied Mathematics, provides the basis for our Impact Case Studies.

#### Renewable Energy and Sustainability

During 2012-2016 LORA applied their theoretical work on multiple objective decision support optimisation and scheduling to marine renewable energy. Having jointly secured the "2OM" project (covering the Channel Interreg zone; southern UK and northern France, with 11 partners), they jointly founded LEANWIND (EU funded, with 31 partners) to develop and apply decision support tools. LEANWIND addressed challenges posed by the entire life-cycle of wind farms including selecting sites, planning, managing supply chains, constructing, monitoring, maintaining, and decommissioning. It spans configuration and scheduling of land-based and port-based infrastructure, servicing by marine staff and routing autonomous service vessels over the Mediterranean and English Channel. Benefits to stakeholders are reductions in cost and environmental impact. Support for organising workshops enabled LORA to build a further relationship with Polaris Consulting Ltd as part of a KTP with Innovate UK. The work generated 15 publications and was supported by an internally funded PhD.

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In Applied Mathematics, Foster established collaborations with Oxford, McMaster (Canada) and Southampton universities and industrial partners including General Motors and Dassault. His work with General Motors provided enhanced theoretical understanding and modelling capabilities that led to new methods to improve the lifetime, performance, safety and reliability of Lithium-ion batteries (see REF3:UoA10Batteries). This is crucial to the future uptake of electric vehicles, contributing to societal goals to reduce emissions and waste, and significantly reduces the time and cost of product development. An EPSRC New Investigator Grant (£310k) allowed the appointment of a postdoc (2020-2023). Foster is part of the Faraday Institute Challenge (award £216k) to support multiscale modelling, in which he is training an additional postdoc.

#### Transport and Maritime Systems, Risk and Security

During 2012-2018, Ouelhadj, Khosravi, and others were supported to undertake research in optimisation, scheduling, heuristics, meta-heuristics and stochastic simulation and (2016-2020) applied this to optimise passenger flow through gate lines (ticket barriers), crucial for efficient throughput of people and for crowd management, reducing congestion and improving safety. Funded by the Rail Safety and Standards Board, with industrial partners including Cubic Transportation Systems Ltd, Transport for London, Arriva UK Ltd, and the Connected Places Catapult, the resulting self-reconfiguring gate line solutions are widely applicable (see REF3:UoA10Gatelines).

The WASP project (in collaboration with Renewable Energy Catapult, L3Harris, Holders Ltd, and SeaRoc Ltd) and AntsOnDeck (in collaboration with Polaris Consulting Ltd, L3Harris, and BMT Argos) support development and optimal routing of autonomous vessels for wind farm maintenance and for defence.

Early-stage institutional support, including visits by a RIS Collaboration Manager (from the Business Engagement Team) to an EU Security brokerage event in Brussels and pump-priming funds for two subsequent visits by Jones to Norway, nurtured a LORA partnership with Arctic and North Atlantic coastguards on the ongoing EU ARCSAR project to tackle transnational maritime threats and enhance safety and security.

To enable focussed collaboration and foster new connections, the School appointed and hosted **Visiting Industry Research Fellows** from our industrial collaborators including Fletcher (Cubic Transportation Systems), Galatioto (Connected Places Catapult), Cheeseman (Offshore Renewable Energy Catapult), Trafford (Fawley Waterside), and Fennessey (BAE Systems Maritime Services).

### **4.3 Wider activities and contributions to research base**

#### **4.3.1 Indicators of wider influence and contribution**

Journal Editorships include Jones (*Mathematical Problems in Engineering* and *Advances in Operations Research*), Foster (guest editor *IOP Progress in Energy*) and Li (guest editor *Pacific Journal of Optimization*). Staff throughout the department peer review for over 50 journals.

Approximately half our staff were invited to present in 2014-2020. Notable examples include Ouelhadj (keynote OR60), Jones (keynote, Spanish MCDM Group Conference), Foster (invited

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talks at German Physical Society Meeting, Oxford IAM seminar series and Fields Institute for Research in Mathematical Sciences), Burrige (Cambridge, Edinburgh, Southampton, Yale and IMA Budapest), Waters (Finite Dimensional Integrable Systems Conference, Barcelona and Laboratoire Dieudonné, Nice), and Cerasuolo (Japan Society for the Promotion of Science, funded by Royal Society, and UNESP Botucatu, Brazil).

Staff represent the institution at events where national and international policies are discussed. Osbaldestin's roles included LMS Representative, Chair of the Institute for Mathematics and its Applications Higher Education Committee, Council Member and Treasurer of the IMA, Chair of the Heads of Departments of Mathematics, and member of the MSOR Subject Benchmark Statement group. Burbanks is Isaac Newton Institute and International Centre for Mathematical Sciences Correspondent, disseminating information about the Mathematics infrastructure and representing the University. Burbanks was a panel member for the joint LMS/IMA Christopher Zeeman Medal (2020).

Ouelhadj is on the Assessment Committees of EU Interreg 2 Seas, France Channel England and of the Netherlands Organisation for Scientific Research on Complexity in Transport and Logistics. She is on the Advisory Boards of Transport for the South East (representing 12 universities), of Solent Transport, and the 2017 Year of Autonomy cluster, led by Southampton's National Oceanography Centre, is treasurer of the Committee of Professors in OR, member of the European Intelligent Transport Forum, Chair of the Southern OR Group, and Southern Regional Representative to the General Council of the OR Society.

Our LORA group leads SCCoE's knowledge exchange activities, organising and chairing 41 major events, producing collaborations and major income from business and local authorities. Regional benefits resulting from this include business investment in satellite applications, plus expanding access to satellite facilities and know-how.

Ouelhadj is Academic Lead for the University's 10-year collaboration programme with NATO, USA. Funding from the University Theme *Security and Risk* helped secure the project that provides training, workshops (6 in 2019 with 100 delegates) and collaborations on topics including optimisation, intelligence and AI, including plenary sessions at I3 (Initiate-Innovate-Imagine) held at NATO, Virginia (Feb 2020). The partnership created collaboration opportunities for the Themes *Future and Emerging Technologies* and *Security and Risk*.

Foster reviews grants for the Natural Sciences and Engineering Research Council of Canada.

Weiss is co-author of the Springer Undergraduate textbook "A Primer on Hilbert Space Theory", downloaded 19,000 times (First Ed., 2016).

#### 4.3.2 Conference organisation

LORA receives support from the OR Society and Southern OR Group for workshops and conferences with industry. Ouelhadj chaired the OR58 Conference (2016) hosted in Portsmouth with record attendance (195 academics, 175 practitioners) and was on organising committees for the 2nd IMA Conference on Mathematics for Robotics (2020), Connected Everything (2017, 2018) and the IMA/OR Society Conference on Mathematics and OR (2017). Song chaired "Emerging Technologies in Humanitarian Supply Chain Management" in the 9th IFAC

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Conference MIM (2019), and sessions in OR58 and OR60, and organised the 12th International ESICUP (2015).

In Applied Mathematics, Cerasuolo organised the mini symposium *modelling epidemics in human and plant populations* at BAMC, Surrey (2017). Weiss is organiser of the 22nd Galway Topology Colloquium to be hosted in Portsmouth (2021) supported by the LMS.