Institution:
University of Essex

Unit of Assessment:
10 – Mathematical Sciences

1. Unit context and structure, research and impact strategy

a) Overview

The Department of Mathematical Sciences (DMS) is currently undergoing an exciting phase of positive transformation. Substantial recent investment has supported an ambitious growth strategy, enabling the Department to achieve its primary goal of having a REF submission to UoA 10 for the first time. These developments have been accompanied by a commensurate increase in research income (46% increase from 2014 to 2020), including over £1.6M for industry- and government-funded projects. As recognition of this successful growth, in 2018 the Department moved to new, purpose-built accommodation within the University's flagship new £18M 'STEM Centre', which provides cutting-edge facilities and an ideal working environment for interdisciplinary research and collaboration. All research submitted to UoA 10 for the University of Essex is produced by members of the Department, which currently comprises 33 academic staff (32 ASER staff, one of whom is submitted to UoA 2), 2 senior research officers, 2 Knowledge Transfer Partnership (KTP) associates, 7 professional services and support staff, 28 PhD students, 243 Masters and 353 UG students who, as a community, deliver on the University's dual-intensive mission of 'Excellence in Research', and 'Excellence in Education'.

The Department's vision is to deliver fundamental research across the areas of pure and applied mathematics, actuarial mathematics, optimisation, data science, and statistical methodology, whilst also leading novel interdisciplinary research and working with industry and external stakeholders to deliver real world impact. Research activity is organised across two groups, 'Data Science' and 'Mathematics', each containing key themes (Data Science: Actuarial Mathematics; Data Science and Statistical Learning; Operational Research; Statistical Methodology. Mathematics: Algebra, Discrete Mathematics and Geometry; Analysis and Mathematical Physics; Mathematical Applications). Extensive interaction between themes and groups provides greater breadth of research, while engagement with high profile institutional research centres hosted at Essex, such as the Institute for Social and Economic Research (ISER), the Institute for Analytics and Data Science (IADS), and the UK Data Archive (UKDA), enable much wider interdisciplinary collaboration. Successful engagement with industry and external stakeholders, including companies such as Hutchinson Ports, Mondaq, MSXi, Ocado, Profusion, and Strike, has led to direct impacts of DMS research in the real world.

b) Research Strategy

Historical context (pre-2014)

Mathematics was one of the founding departments of the University of Essex. The department was reinvigorated when a long-term strategic plan to develop mathematical sciences at Essex was initiated in the early 2000s. This was focused on developing research strengths in both fundamental mathematics with wider interdisciplinary applications, and on the emerging discipline of data science. The strategic plan was highly successful, with key appointments such as **Codling**, **Harrison**, **Lausen** and **Williams** joining existing colleagues (**Higgins**, **Penman**, **Salhi**, and **Vernitski**). Despite this success, the Department remained relatively small and hence staff were submitted to other UoAs (7 staff to UoA 11 and one to UoA 19 for REF 2014). In 2013, the University approved a growth plan for the period 2014-20 in order to achieve the key strategic objective of building a viable research base for a full REF submission to UoA 10.

Strategy and objectives (2014-20)

The DMS research strategy throughout the 2014-20 period combined ambitious growth with supporting and developing new and existing staff, enabling them to improve the quality and impact

of their research, and to increase grant income. The objectives supporting this research strategy, the related outcomes and achievements of the 2014-20 period, and the operational mechanisms in place to ensure continued delivery, include:

Objective 1: Increase the number of academic staff and submit to REF UoA 10 for the first time. To enable a DMS UoA 10 REF 2021 submission, a highly ambitious growth plan was initiated in 2013, supported by substantial investment from the University. This led to significant and sustained recruitment of new staff (21 academics appointed since 2013), quadrupling the number submitted since 2014 (REF 2021: 31 staff in UoA 10, and one in UoA 2).

Objective 2: Support and development of new and existing staff. With rapid growth, a key strategic focus was to make sure that all academic staff (new and existing) were fully supported with their research and wider professional development in order to fulfil their potential. Evidence of the wider success of this approach within the REF period includes 8 academic staff achieving permanency and 11 staff achieving promotion (of whom 5 were promoted to Professor) (**Section 2**).

Objective 3: Improve the depth, breadth, and quality of research. The rapid growth of the department during this period meant that it was possible to develop both the strength in depth of existing research groups, themes and specialisms (for example **Algebra**, **Discrete Mathematics and Geometry** or **Data Science and Statistical Learning**), whilst also increasing the breadth of research within the department by creating new groups and themes in strategically focused areas (for example in **Actuarial Mathematics** or **Analysis and Mathematical Physics**).

Objective 4: Increase and diversify grant income. A key strategic objective was to increase both overall grant income and to widen the diversity of grant-holders and funding streams within the department. This strategy was successful with (for the period 2014-20) 12 large research grants (>£50k) awarded or held by 12 academic staff (compared to 7 large grants held by 4 staff in the period 2008-2014), with headline income totalling £3.8M received from a diverse range of funders including UKRI (NERC, BBSRC, ESRC, EPSRC), Leverhulme Trust, NIHR, Innovate UK, and learned societies (**Section 3**).

Objective 5: Increase engagement with industry, stakeholders, and the public to maximise impact. To maximise the impact of DMS research, a key strategic objective was to expand and develop the number of industrial partnerships and collaborators. Between 2014 and 2020 the department received six KTP awards (totaling £1,118,430) in collaboration with companies Mondaq (twice), MSXi, Ocado, and Profusion (twice) compared with one (Hutchinson Ports) in the previous REF cycle (**Section 4**). In addition, the Department received £457,552 to work with Essex and Suffolk County Councils in the Catalyst Project (awarded in 2015). The number of academic staff involved in directly funded industry engagement or collaboration has increased from 3 (2008-2014) to 8 (2014-20).

Objective 6: Improve department facilities and infrastructure. Dramatic and sustained growth over the 2014-20 period created a strategic need for new departmental space This was provided in 2018 when the department moved into the entire top floor of the STEM Centre, providing an ideal working environment for trans-disciplinary research and collaboration **(Section 3)**.

Implementation of the departmental research strategy is led by the Department Steering Group (DSG, including the Head of Department (HoD), Director of Research (DoR), Director of Impact (DoI), and Postgraduate Director). Their work is supported by the DMS Research Management Group (which includes lead and early career academics from each of the main groups and themes). Central support is provided via the Research and Enterprise Office (REO) who have a dedicated grant support team, dedicated KTP team, as well as individual staff with roles specifically focused on supporting Knowledge Exchange (KE) and impact activities in mathematical sciences. Faculty support is provided by the Deputy Dean for Research (DDR) (Science and Health), a role currently undertaken by **Codling** on a secondment from the department. Further support and guidance on DMS research strategy are provided by the Essex Mathematical Sciences Advisory

Board, which includes national and international external experts and advisors from both academia and industry, and meets at least once per year.

Future plans and objectives (2021 onwards)

Strategic growth and transformation over the 2014-20 REF period have enabled the department to achieve its aim of conducting world-leading research with maximum impact, while simultaneously fostering a collegiate and intellectually stimulating working environment, supported by significant and sustained investments in people, infrastructure and facilities. Moving into the next REF period, the Department will continue to expand the breadth and depth of its research base and wider interdisciplinary and industry collaborations in order to take a leading role in research that tackles major contemporary and future societal and scientific challenges. The central aims described in **Objectives 1-6** from the period 2014-20 will be retained but refocused to suit the developing needs of the department, institution, and wider environment. In particular, specific new plans and objectives include:

- **(Future Objective 1) Further new appointments**, including leadership roles within the Data Science research group to strengthen links to cross-University data driven research in Health and Life Sciences, Social Sciences and Humanities.
- **(Future Objective 2) Expansion of the Mathematics research group** with new appointments to broaden the breadth of research across the department, and of its interdisciplinary applications and societal impact, and to strengthen existing themes.
- **(Future Objective 3) A new research group focused on Mathematics Education**, to be created and led by Vernitski and including Saker (Professor of Mathematics Education at Essex).
- **(Future Objective 4) A specific COVID-19 plan** to ensure all academic staff are supported during and after the current pandemic period. This will include focused support on the large cohort of early career academics recently appointed, to ensure they fulfil their potential and that future research leaders are identified and supported.
- **(Future Objective 5) Securing involvement in one or more DTCs/DTPs** either as lead or in collaboration with partner institutions is a key ongoing objective, together with increasing the number of PhD students from other sources.
- **(Future Objective 6) Increase research i**ncome, with an emphasis on increasing DMS contributions to large cross- and inter- institutional research consortia.
- **(Future Objective 7) To increase and further develop working relationships with industry and wider society** to deliver real world impacts of DMS research.

c) Structure

Research activity is structured across two main groups reflecting the department's dual focus on both data science and fundamental mathematics: Data Science (with four themes), and Mathematics (with three themes).

Data Science (17 current members, and one submitted to UoA 2):

The Data Science group is immersed in an outstanding environment for research and delivering impact, exemplified by the group achieving 7 Knowledge Transfer Partnership (KTP) awards in this REF period. The group is linked to several renowned national data institutes hosted at the University of Essex including the UKDA, the ESRC-funded Business and Local Government Data Research Centre (BLG DRC), the ESRC-funded ISER, IADS, and the National Institute for Health Research (NIHR) East of England Research Design Service. Staff in each of the four themes regularly collaborate, facilitated by a weekly research group seminar series. The **Actuarial Mathematics** theme consists of four early career researchers (**Fadina**, **Hu**, **Liu** and **Wong**), and an established and internationally recognised expert on actuarial and financial modelling (**Vrontos**). Theme members conduct multidisciplinary research in the broad areas of actuarial science and finance, including predictability, asset-liability management, risk management and risk theory, mathematical finance, financial data science and applied probability in actuarial science

and queueing systems. Applications include prediction of financial and macroeconomic series, equity premium, recession indicators, Bayesian methods for mortality modelling and forecasting, optimal insurance pricing, optimal risk transfer and robust insurance mechanisms, term-structure models, affine stochastic processes, Gaussian processes, extreme value theory and ruin theory. The **Data Science and Statistical Learning** theme includes early career academics (**Bailey**, **Gutierrez-Roig**, **Hadjiantoni**, **Mahmoud**), established academics (**Harrison**), and an internationally recognised leader of the data science community (**Lausen**). Theme members work on a range of data science methodologies covering artificial intelligence, statistical learning, computational statistics, epidemiology, bioinformatics and environmental statistics. Specific methodological developments include ensemble methods, deep learning and their applications, resampling based assessments of uncertainties of models in clinical research, numerical algorithms for the estimation of multivariate models for the analysis of functional data, dimensionality reduction machine learning algorithms for the analysis of text data, statistical analysis of telemetry data, and algorithms for urban dynamics and computational social science. The theme has direct collaborations and partnerships with the health sector, digital industry and government. The **Operational Research** (OR) theme includes two early career academics (**Amanatidis**, **Meng**), a mid-career academic (**Yang**), and an internationally acknowledged expert in nature-inspired heuristics (**Salhi**). Theme members conduct multidisciplinary research in the broad areas of OR and mathematical modelling including linear and nonlinear programming, combinatorial optimisation, deterministic and stochastic dynamic programming, algorithm (heuristics) design and analysis (including the novel Plant Propagation Algorithm (PPA, developed by **Salhi**), implementation of algorithms, data analytics and applications in portfolio selection, labour scheduling, green distribution, and predictive modelling. The **Statistical Methodology** theme consists of **Rabhi** and **Bao** (submitted to UoA 2), early career academics, and **Dai**, an established expert on the interface between Monte Carlo techniques and Bayesian analysis; **Perperoglou** was also a member of the theme until 2019. Theme members work on a broad range of statistics and applied probability topics, including Bayesian statistics, longitudinal and survival analysis, causal inference and applied probability. New methodological development includes computationally intensive Bayesian Modelling, exact Monte Carlo simulation such as Monte Carlo (or Bayesian) Fusion methods, nonparametric estimation for bivariate survival functions, semiparametric and nonparametric methods for length-biased and censored data.

Mathematics (14 current members):

The Mathematics group has expertise across many areas of pure and applied mathematics, ranging from algebra to mathematical biology. Colleagues work closely together across themes, including shared PhD students and joint grant applications over the 2014-20 period. The growth of research activities in the group is evidenced through the recent appointment of two (postdoctoral) Senior Research Officers funded through Leverhulme Trust grants. A weekly seminar series encourages further inter- and intra-group discussions and collaborations. The **Algebra, Discrete Mathematics and Geometry** theme comprises early career academics (**Claridge**, **Litterick**, **Martinez-Garcia**), established research active mid-career academics (**Penman**, **Vernitski**, **Williams**), and an internationally recognised authority in semigroup theory and Premio Peano prize-winning author of popular science books (**Higgins**). The recent departmental growth strategy has enabled an expansion in the theme's scope, doubling its size from a core base of expertise in semigroup theory, combinatorial group theory, graph theory and combinatorics to now include researchers who work in algebraic geometry, finite group theory, and applications of finite field theory to network coding. The **Analysis and Mathematical Physics** theme comprises two early career academics (**Akman**, **Papamikos**), and an established mid-career academic (**Grahovski**). Theme members work on a broad range of topics in Analysis and Mathematical Physics, including discrete and continuous integrable systems, Lie groups, Lie algebras and symmetries, analysis of PDEs, Harmonic analysis and Potential theory, algebraic methods in differential equations, and geometric analysis. The **Mathematical Applications** theme comprises early to mid-career academics (**Antonopoulos**, **Savostyanov**) and senior academics internationally recognised in their fields of expertise (**Codling**, **Susanto**); **Noferini** was also a member of the theme until 2019. Theme members work on topics ranging from numerical mathematics and applications of linear algebra, through dynamical systems and nonlinear waves, to mathematical biology. Specific topics

include complex systems, network analysis, network inference, random walk theory, collective behaviour, population dynamics, pattern formation, dynamical systems, soliton theory and nonlinear waves, nonlinear and atomic optics, spinor Bose-Einstein condensates, fluid mechanics, numerical mathematics, low-rank tensor product approximations, linear and multilinear algebra, matrix analysis, and the design of efficient numerical algorithms.

Interdisciplinary research

The department has continued to grow strong research links to computer science, life sciences, health and social care, medicine, business, local government and humanities during 2014 to 2020 (**Section 4**). With the future research objectives on Doctoral Training Centres (**Future Objective 5**), cross- and inter- institutional research consortia (**Future Objective 6**) and working with industries and for society (**Future Objective 7**) the department continues to have a strong agenda on interdisciplinary research.

d) Research Impact

Maximising the impact of DMS research has been a central aim of the departmental research strategy (Objective 5) throughout the 2014-20 REF period; specific strategic mechanisms include:

- **Embedding an impact agenda within the department**. A key aim has been educating and supporting academic staff on how to deliver impact from their research, and this is now embedded within the research culture of the department (**Section 2a**).
- **Faculty and REO support**. Central support for impact work is provided through a dedicated team within the REO, including roles that are specifically focused on supporting Mathematical Sciences staff and projects with KE activities, as well as specific support for research impact and REF impact case studies (**Section 2a**).
- **Internal and external funding**. Specific impact activities are supported through both internal and external funding mechanisms. Internal funding acts as a pump-priming mechanism for staff to develop external funding bids such as KTPs, Innovate UK, and other impact related funding (e.g. HEFCE). Over the 2014-20 REF period DMS academics received over £1.6M for industry and government related research (**Sections 3 and 4**).
- **Wider engagement and knowledge exchange with industry, stakeholders, and the public**. Increasing direct engagement with industry partners has been crucial in delivering the impact strategy. A range of activities have been undertaken over the 2014-20 period including regular impact workshops, and hosting and attending high profile public engagement events (**Section 2a**).

The three impact case studies selected for this submission are exemplars of the success of the departmental impact strategy over the 2014-20 REF period. All three cases are based on underlying DMS research that was developed through initial internal impact support for key staff involved, followed by external funding mechanisms (KTP, HEFCE), alongside direct industry engagement and collaboration, leading to realisation of impact. Moving forwards, a number of other projects have been following the same impact development strategy, with ongoing direct industrial collaboration through externally funded projects (**Sections 3 and 4**), which should directly lead to impacts in the next REF cycle.

e) Open Research, Integrity and Ethics

Open research is embedded in the shared philosophy of the department. Opportunities to discuss the department research strategy and policies are available to all staff at departmental meetings, research away days, and at Research Committee for those involved. Minutes and recommendations from these meetings are circulated to ensure an open research environment. Open access publishing (of both outputs and data) is promoted and encouraged through a range of mechanisms. All output publications (not just those submitted for REF) are published through the University's Research Information System (RIS). From 2014 to 2021, 329 articles were deposited in the University's Institutional Repository, among which 205 were Green open access and 83 Gold

open access. The University also provides a central block grant for Gold Open Access publishing of specific outputs linked to UKRI-funded projects, and has an increasing number of read-and-publish agreements with publishers such as Wiley and Sage. Many staff members, including all members of the Mathematics group, post preprints on the ArXiv repository. The department also follows the UKRI Concordat on Open Research Data, and several members have published open access data sets (e.g. **Codling's** cow tracking movement data sets) or submitted R packages to CRAN (e.g. propOverlap & OTE). **Mahmoud** leads the University activities in relation to reproducibility as part of the UK Reproducibility Network (UKRN), liaising with other institutional leads and the steering group of the UKRN to facilitate the delivery of its aims.

The University conforms to the Concordat to Support Research Integrity, and has developed the *University Code of Good Research Practice*, which is provided to all staff as part of training and induction. This includes explicit reference to the Committee on Publication Ethics (COPE) recommendations on publication and authorship; the department is committed to ensuring all contributors, including PhD students, gain appropriate recognition and are included in research outputs. Overall oversight of research integrity is provided by REO's Research Governance and Planning Manager, who ensures compliance with the code as well as other external legislation and funders' requirements across all projects within the department. The department has a robust ethics procedure managed by the departmental Ethics Officer and by the central University Ethics Committee and its three Ethics Sub-Committees (ESC); **Codling**, as DDR (Science and Health) is the current chair of ESC 1.

2. People

a) Staffing strategy and staff development

The transformative success of the department can be attributed to the specific objectives relating to staffing and staff development within our wider research strategy: investing in and increasing the number of staff within the department, by appointing the right balance of early career and established academics (**Objective 1**); supporting all staff within the department, enabling them to develop and achieve their potential in delivering the highest quality research and impact (**Objective 2**).

Staffing strategy

The departmental staffing strategy balances the need to facilitate excellent research and impact, whilst also supporting excellent research-led teaching and postgraduate supervision. The department Senior Management Team (including the HoD, DoR, DoI, PG Director, and a representative of the department Athena SWAN committee), working with the department Research Committee, recommend areas for new appointments based on both the strategic needs of each research group and theme, and the need to support teaching. Examples of strategic growth areas over this REF period include the creation of the **Actuarial Mathematics** research theme (6 new staff, one of whom has since left Essex) and the **Analysis and Mathematical Physics** theme (3 new staff). The wider strategic context around staffing is also considered when planning new appointments. For example, in 2013 the department identified that most existing staff were established mid-career or senior academics, and hence a key focus during this period has been to appoint early career academics to ensure continuation and succession within the department. In total, 21 new academics have been appointed since 2013, 19 of whom were appointed at the Lecturer level. An additional strategic focus throughout this period, identified as part of our Athena SWAN review and planning, was to improve the gender balance of the department. This has been highly successful with the number of staff identifying as female increasing from none at the start of 2013 to six in 2020 (with one promoted to Senior Lecturer in this period).

Recruitment

Once a position has been advertised, a broad panel (comprising members of the Senior

Management team, research theme leaders, and including at least two staff identifying as female) identifies candidates to be shortlisted. Shortlisted candidates deliver a research seminar and lecture to the whole department before being interviewed by a panel of 5 academics, including at least two staff identifying as female. For senior staff appointments (SL and above) successful applications are also reviewed externally to assess the candidate, while for Professorial posts a separate recruitment process chaired by the Vice Chancellor is implemented.

Staff development and support

The department strategy and policies around staff development are focused on enabling staff to maximise their potential, progress in their career, be rewarded for high performance, and to promote a collegiate and vibrant research environment (**Objective 2**). The University has recently initiated a new Researcher Development Framework (RDF) for academic staff at all stages of their career based on the *Vitae Researcher Development Framework*. Central to the Department's aim to facilitate and deliver 'Excellence in Research' is providing staff with sufficient time to undertake research and impact activities. The increase in the number of academic staff within the department as part of the growth strategy (**Objective 1**) has had the follow-on benefit of allowing a reduction in both teaching load (from a typical load of 3 modules per FTE in 2014 to 2 modules per FTE or less in 2020) and administrative burden on staff. A transparent Workload Allocation Model (WAM), which includes a specific protected allowance for research time, is used by the HoD to allocate teaching and administrative duties. Each academic is provided £1500 annually to support their research and impact activities. Further direct support to staff is also provided via departmental PhD scholarships (9 awarded within DMS in the period 2014-20) and Faculty interdisciplinary PhD scholarships (8 awarded to DMS in this period, including co-supervised projects).

All academic staff are assigned a formal academic mentor within the department; informal mentoring and support is provided by each research theme leader. Staff also have access to institutional mentoring schemes such as the Essex Peer Support Network, and cross-institutional schemes such as the recently formed Eastern Academic Research Consortium (Arc) mentoring scheme, involving the Universities of East Anglia, Essex and Kent. Annual Performance Development Reviews (PDR) are held between the HoD and each individual academic to evaluate training needs, set research objectives, and discuss their career development aims, including applications for permanency or promotion. Promotion (and permanency) applications are evaluated as part of the Annual Review process in two stages: first via the department Senior Staff Committee, where feedback is provided to improve applications, and secondly via the University's Academic Staffing Committee which makes a final decision. During this REF reporting period, 5 DMS staff have been promoted from Senior Lecturer (SL) or Reader to Professor, 3 from SL to Reader, and 3 from L to SL. Of these, 4 staff had also achieved permanency in the same time period, highlighting their rapid progression.

New appointments and early career academics

All new academics undergo a three-year 'Pathway to Ppermanency' period designed to ensure a successful transition to a permanent role. All the support mechanisms described in the previous section are available to pathway to permanency staff, who receive prioritisation for reduced teaching (typically 1.5 modules per year rather than 2) and administrative loads, and for departmental PhD scholarships. All new staff are assigned a 'Pathway to Permanency' supervisor (in addition to their academic mentor), and together they develop an individual-specific plan for research, education, leadership and training targets, which is subsequently reviewed and approved by the HoD and Faculty Dean. Progression is assessed in a supportive manner via 18 and 36 month reviews. Each year, pathway to permanency staff can opt to apply for early permanency through the standard Annual Review process. Significant mandatory and optional training is available via the University's Occupational Development section to prepare new staff for their roles. All new academic staff are required to attain Fellow of the Higher Education Academy (FHEA) via the University's *CADENZA* programme. During this REF period, all 8 DMS staff (including 2 staff who identify as female) who applied for permanency achieved it successfully (with one achieving early permanency). Reflecting the success of these individuals and the contribution they have

made, 4 (including one who identifies as female) have subsequently achieved promotion to SL or Reader, two of whom are also now undertaking key leadership roles within the department (**Dai**: DoR; **Yang**: PG Director).

As integral members of the department, postdoctoral research staff and research associates have access to the same central training resources as academic staff, and also undergo the standard PDR and Annual Review Processes (but evaluated by their line manager rather than the HoD). Given the fixed-term nature of their roles, specific support is given centrally and via line managers for ongoing career development and employability to ensure that staff are able to progress into independent research careers. During this REF period 4 postdoctoral staff and 10 KTP associates have been employed within DMS.

Support for impact and exchanges between academia and industry

A key element of the overall research strategy for this period has been embedding an impact agenda into the culture of the department (**Objective 5; Section 1e**). The DoI has overall oversight and leads on the delivery of the impact strategy. Academic staff are encouraged and incentivised to undertake impact work through specific time allocations in the department workload model (WAM), in addition to teaching buy-out enabled through external income. Regular impact meetings and workshops are led by the DoI to support departmental impact activities, as well as providing specific support to individual projects. Central support for impact work is provided through a dedicated team within the REO, including roles that are specifically focused on supporting Mathematical Sciences staff and projects with KE activities. Further direct support for impact activities is provided through internal funding mechanisms (**Section 3**) that act as a pump-priming mechanism for projects to develop external funding bids. Supported by the REO, who communicate upcoming funding calls and assist in applications, academic staff are encouraged to apply for KTPs, Innovate UK, and other impact related funding (e.g. HEFCE) (**Section 3**). The 2012-16 BBSRC grant awarded to **Codling** (Cow Tracking Project) included a 3-month placement for the postdoctoral researcher with Omnisense Ltd (Cambridge) in 2016. A range of further engagement activities have been undertaken over this period including an informal 'Maths Breakfast' with local business leaders, regular impact workshops hosted within the department for industry partners and other stakeholders, and hosting and attending high profile public engagement events (**Section 4**).

Research Leave

All academic staff (ASER) accrue research leave entitlement at the rate of one term of leave for every 6 terms worked (equivalent to 2 full years). Staff involved in senior management roles (HoD, Dean, Deputy Dean, etc.) accrue leave at twice the standard rate, to be used at the end of their term of office. Staff can apply to take up to a maximum of three terms of leave (one full year) in a single sabbatical. Applications are reviewed and prioritised by the HoD and Research Committee in a transparent process. Throughout the current REF period, 14 DMS staff have taken a total of 33 terms of leave (eight staff for a full year; four staff for two terms; one for one term).

Recognition and Reward

Staff bringing in external grant income are directly rewarded in two ways: firstly, additional research time in the WAM is allocated (teaching buy-out) based on the proportion of salary the grant covers; secondly, the University runs a Education and Research Incentive Scheme where a proportion of the grant indirect costs (for UKRI grants) are returned directly to the investigator and can be taken either as additional salary or to supplement their research. At the institutional level, research and impact are supported and championed through a range of high-profile awards and events, including the annual 'Celebrating Excellence in Research and Impact Awards', where **Yang** recently won 'Best Research Impact in Enterprise and Innovation 2020'.

b) Research students

Recruitment of research students

Research students are recruited from a range of backgrounds, including from within the department. The department does not currently hold any DTC or DTP awards, although several staff have co-supervised students on other DTCs in which Essex participates. Most students are either funded through departmental PhD scholarships (9 awarded within DMS in the period 2014-20) and Faculty interdisciplinary PhD scholarships (3 awarded directly to DMS in this period, with a further 5 co-supervised by DMS academics) or are self-funded (or via national governments).

Monitoring and support mechanisms

The Postgraduate Director has overall oversight of all progress monitoring and training activities for research students, in order to ensure successful completion (37 students successfully obtained their PhD in this REF period) and that students can transition into employment. All students have a main supervisor who acts as mentor during their studies; the department also strongly encourages co-supervision (more than 15 students in this period), particularly across research groups or for interdisciplinary projects. Student progress is monitored through formal Supervisory Board meetings (every 6 months) and measured against formal published milestones; training needs are also identified at each board meeting. A confirmation board is held after 12 months, where the student is formally confirmed onto the PhD degree, after ratification by the departmental Research Student Progress Board and the central Graduate School. Peer-support mechanisms are also encouraged within the department and students have self-organised schemes to share experiences and good practices, small workshops, and reading groups within their areas of study.

Skills development and future career

The University Graduate School has overall responsibility for PG research student training at the institutional level and has developed a comprehensive development programme (*Proficio*) that offers training in both scientific and generic research skills and professional development. As part of the *Proficio* programme, all DMS research students are provided with £3500 (£1000 of which is provided by the department) which they have full control over spending on their own training courses, workshops, and external conferences. Students identify training needs throughout their PhD, and this training log is reviewed by their Supervisory Boards. The department has created bespoke 'R' and 'Matlab' *Proficio* training (open to all students across the University). Students also use their *Proficio* funds to attend external courses such as 'Academy for PhD Training in Statistics' or the MAGIC network, as well as attending and presenting at national and international conferences (>50 occasions in the 2014-20 period). Research students are expected to attend and participate in the weekly research group seminars and the networking session afterwards; all final year PhD students give a department seminar on the findings of their research. Throughout their PhD, students are encouraged to think widely about their employability and future career aims, and the department actively promotes wider research networks and opportunities, and provides tailored career advice from supervisors and senior colleagues. All PG students are offered GTA/GLA teaching opportunities and are provided with training and support that enables them to run or support successful sessions. After graduating, PG students have excellent career prospects (at least 10 recent PhD graduates now hold permanent academic positions), exemplified by **Mahmoud** and **Bailey** who are now both members of academic staff in the department.

c) Equality and diversity

Evidence of commitment to equality and diversity

The University of Essex recognises the value of diversity and is committed to equality of opportunity, with clear policies supporting these aims for all staff and students at the institutional level. The department has embedded these policies, and the principles behind them, into strategic planning over this period and this has directly led to a number of clear successes:

- The number of academic staff identifying as female has increased from zero (2013) to six (2020).
- The most senior academic identifying as female (**Yang**) achieved permanency and promotion to SL in this REF period, and has been undertaking a senior leadership role (PG Director).
- The department has been awarded the Athena SWAN Bronze Award in 2018 (and is preparing to apply for the Silver Award).
- The department is a registered Supporter of the London Mathematics Society Good Practice Scheme.
- From 2017/18 to the start of the pandemic in 2020, the Department hosted 36 speakers identifying as male and 36 speakers identifying as female, matching ongoing commitments on gender balance made within the DMS Athena SWAN Bronze application.

DMS is a very international department with staff from diverse ethnicities, nations and cultural backgrounds (68% white and 32% other ethnic background). Equal opportunities in career progression and promotions, submission of funding applications, access to internal funds, recruitment for departmental leadership roles, conference attendance, sabbaticals, and training is given to all staff, including part-time and fixed term staff. Gender and distribution of workload across departmental committees and outreach activities is monitored to ensure equality of workload. The department has a dedicated Inclusivity and Disability (I&D) Officer who supports all staff and students to ensure everyone has equal opportunity to conduct research productively. The I&D Officer gives inclusivity-centred talks at all induction events (for both staff and students), and liaises with the University on behalf of students and staff with protected characteristics. Every member of staff is required to complete training on equality and diversity within six months of starting their roles (and every 3 years for existing staff). The department has an open and transparent workload model, which can be adjusted to support staff returning from periods of leave, those with disabilities, medical issues, and/or caring roles. Staff with specific needs or disabilities are also supported with adjustments to their work environment (desk, chair, computer, etc.) where appropriate. Departmental funding is also available to staff with additional needs around conference attendance or other research requirements (e.g. because of caring responsibilities). The wellbeing of all staff is a priority and the department promotes flexible working arrangements and has implemented a 'core working' period (10am-3pm) where all meetings are scheduled to help staff with work/life balance.

Equality and Diversity in REF submission

The department REF Research Management Group (RMG) includes a representative of the Athena SWAN committee, the I&D Officer, as well as a senior female academic (**Yang**) in her role as PG Director. The RMG scrutinised the preparation of the departmental REF submission to ensure that due regard to equality and diversity issues was paid at all stages. The selection of the output portfolio is balanced across all research groups to ensure adherence to the equality and diversity policies as set out in the University Code of Practice. During recruitment of new staff throughout this REF period, marketing materials always explicitly encourage applicants with protected characteristics to apply (especially from groups that are underrepresented in mathematical sciences), and every effort is made to have diversity as one of the criteria for appointing interview and selection panels.

3. Income, infrastructure and facilities

a) Income

Strategy to increase and diversify income

During the 2014-20 REF period the department has increased its focus on attracting external funding with two complementary aims (**Objective 4**): i) increase total external income; and ii) diversify income streams (in terms of funding sources and individuals holding grants). New

department policies were developed during this period to achieve these strategic aims:

- All staff are expected to be involved in developing a grant proposal each year as either PI or co-I. Progress is discussed during the annual PDR process, and necessary support provided.
- All newly appointed staff are expected to submit two substantial grant proposals (typically >£150K) during their 3-year pathway to permanency period. Direct support for grant-writing is provided to such staff, who are also encouraged to be co-I on grants led by established staff.
- Additional time buy-out and workload reduction is provided to staff holding external grants in the department WAM.
- Systematic internal review of all applications is undertaken by the department Research Committee before submission.

Additional central support is provided by the REO who communicate upcoming funding calls from research councils, industry and other major research funders, and assist in finalising applications. The University provides various internal grants on a competitive basis for piloting new work, developing research grant applications, supporting workshops and other follow-on impact activities, and to buy-out staff time. These include Challenge Labs, Eastern Arc fund, Global Challenges Research Fund, Impact Acceleration Account funding, and Innovation Vouchers, ranging from £5k to £25k. The department has focused on these internal sources as a strategic 'pump-priming' mechanism to develop successful external grants (£110,000 total internal funding over 8 awards, including two awards totalling £21,000 to staff identifying as female), particularly those linked to industry partnerships. Specific internal awards (>£5k) during this period include £14,007 awarded to **Yang**, which directly led to the Ocado KTP; £10K for a consortium involving **Dai**, the social care company Provide, and the local NHS Dental Network, which led to Healthcare Impact Partnerships applications; £10K for a consortium involving **Harrison** and Public Health England; £10K for a consortium involving **Meng** and the NHS; £7.5K for a consortium involving **Bao**, **Harrison** and **Rabhi** with Essex County Council; £25K for a GCRF project involving **Mahmoud**, **Harrison** and **Lausen** with Egyptian health researchers; as well as a number of smaller awards (<£5k) for other pilot work or impact-related activities.

External income success

The departmental objectives around external income (**Objective 4**) were successfully achieved with an increase in total external income to more than £3m in 2014-20 across 13 large awards, including £1.118m of industry income (**Objective 5**). This compares to total external income of £1,330,000 in 2008-13 across 7 large awards (>£50k). Importantly, income was diversified with more staff winning grant awards (10 staff with external income in 2014-20, including 1 female staff; 4 in 2008-13) and from a wider range of sources (7 funding bodies in 2014-20; 4 in 2008-13). Specific highlights of awards in this period include:

- Six large KTP grant awards in the Data Science research group: Mondaq (£190,521+£159,900, 2016-22, PI: **Lausen**); MSXi KTP (£192,440, 2017-20, PI: **Salhi**); Ocado KTP (£184,632, 2018-20, PI: **Yang**); Profusion KTP (£214,992 + £175,945, 2015-22, PI: **Lausen**).
- Catalyst Project funded by HEFCE (£2.2m, co-Is: **Dai**, **Vrontos**) and the BIAS: Responsible AI for labor market equality project funded by the ESRC UK-Canada AI Initiative scheme (£0.5m, Essex-PI: **Dai**). Supporting role in the Business and Local Government Data Research Centre, University of Essex (ESRC, headline figure £5m + £1.2m, 2014-22 named researchers: **Lausen**, **Salhi**).
- 2 large Leverhulme Trust grants led by the Mathematics research group: 'Machine learning for recognising tangled 3D objects' (£196,267, 2020-23, PI: **Vernitski**) and 'Searching for gems in the landscape of cyclically presented groups' (£177,486, 2018-2021, PI: **Williams**).
- Two large interdisciplinary UKRI grants supported by the Mathematics research group: 'Spatially encoded telecoms and quantum technologies using spin-enabled all-optical switching' (EPSRC, £675,876, 2015-19, co-I: **Susanto**); 'Novel Animal-Mounted Sensor

Technology to Improve Efficiency and Sustainability' (NERC, £252,625, 2017-18, co-I: **Codling**).
- Numerous small grants for conferences, workshops, exchange visits, etc., from learned societies including LMS and IMA.

b) Facilities and infrastructure

STEM Centre

The transformative growth of the department over the 2014-20 period necessitated new departmental space for staff and students (**Objective 6**). The STEM Centre includes laboratories, computing facilities, event space, a science café, and meeting rooms, and hence provides an ideal working environment for inter-disciplinary research and collaboration. The building has achieved a 'Very Good' BREEAM sustainability rating and is designed to be as inclusive as possible, including step-free access for all floors. The top floor of the building provides DMS staff and students brand new office space (adapted for individual staff needs), PhD student desks and computers, social meeting space, and associated support facilities. The department has already taken advantage of the facilities, hosting external industry impact partners, and for research seminars and conferences.

High-Performance Computing

The University provides High-Performance Computing (HPC) support via CERES, a computational cluster built using the Rocks Clustering Solution with CentOS Linux. For computational purposes, the cluster has 1008 64-bit processing cores using a mix of Intel E5-2698, Gold 5115, & Gold 6152 CPUs on a number of dedicated servers each with between 512Gb & 1.5Tb RAM. Storage is provided by a set of storage nodes providing 440Tb of storage. Each computational node has hundreds of open-source software packages and libraries installed plus proprietary packages such as MATLAB, Gaussian, Amber, NAG, and GAP. A technician provides support for all DMS staff and research students. The HPC cluster is used by staff across both DMS research groups; direct outputs and ongoing research include: **Bao**, **Dai** and **Harrison** in their interdisciplinary research analysing 3D-HiC data using Hidden Markov Random Fields; **Dai's** research in Monte Carlo Fusion and Bayesian Fusion; **Lausen's** research on developing new tree based classification ensembles and deep learning; **Vrontos's** research in financial data science models; **Williams'** research in proving that certain groups defined in terms of group presentations are infinite and hyperbolic.

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

a) Academic collaborations and wider contribution to the discipline

Collaborations and networks

DMS is an institutional member of the European Association for Data Science (EuADS) and DMS staff have engaged in a number of exchange visits as part of institutional partnerships via the Young European Research Universities Network (YERUN) and the Young University for the Future of Europe (YUFE) alliance. All staff are allocated time within the department Workload Model, and an annual budget of £1500, to undertake networking and wider scholarship within the discipline. Regular weekly seminars for each of the research groups enables external academics to visit the department, while DMS staff organise and contribute to a wide range of external workshops, conferences, and networking events (details in next section). These supporting mechanisms have enabled DMS staff to develop a number of 'productive' collaborations.

Notable collaborations include **Akman's** work with **Tatiana Toro** (University of Washington) on the solvability of Dirichlet problem for linear elliptic PDEs on rough domains; **Antonopoulos's** work with **Athanasios Fokas** (Cambridge) on the dynamical complexity in the *C. elegans* neural network; **Codling's** work with **Mark Lewis** (Alberta) on novel random walk models of animal

movement applied to grizzly and polar bears, and with **Iain Couzin** (Konstanz) on models of animal collective navigation; **Dai's** work with **Professor Gareth Roberts** (Warwick) on Bayesian Fusion; **Grahovski's** work with **Alexander Mikhailov** (Leeds) on noncommutative discrete integrability, and with **Vladimir Gerdjikov** (Sofia) on multi-component integrable systems and the theory of spinor Bose-Einstein condensates; **Lausen's** work with **Peter Flach** (Bristol) on data science in Europe and on founding the European Association for Data Science (EuADS) in 2015; **Martinez-Garcia's** work with **Cristiano Spotti** (Aarhus) and **Patricio Gallardo** (UC Riverside) on the extension of the moduli continuity method to log K-stable pairs, as well as his work with **Ivan Cheltsov** (Edinburgh) on the study of K-stability of polarised Fano varieties and log pairs on surfaces; **Susanto's** work with **Panayotis Kevrekidis** (UMass Amherst) on nonlinear waves in various physical settings and phenomena; **Williams'** work with **William Bogley** (Oregon State University) studying new families of cyclically presented groups. During this period DMS staff have also published with, or had projects funded with, academics from more than 35 countries across all regions of the globe.

Our international collaborations have been supported by a range of domestic and international organisations: University of Essex International Visiting Scholar Fund; British Council; Heilbronn Institute for Mathematical Research; International Centre for Mathematical Sciences; London Mathematical Society; Newton Fund; CONFAP-q; Academy of Finland; Institut Henri Poincaré; Bielefelder Nachwuchsfonds; Carl-Zeiss Stiftung; German Research Foundation (DFG); Hausdorff Research Institute for Mathematics; Humboldt Fellowship; COST; American Institute of Mathematics; Institute for Computational and Experimental Research in Mathematics.

Interdisciplinary research and collaborations

The department has a long history of research applying mathematical and data science approaches to the wider life sciences. **Bailey** is a co-founder of the interdisciplinary ANIMATE (ANImal Movement AT Essex) research group, which links researchers across the University, with partner organisations such as CEFAS. **Codling** is co-lead on the 'Cow Tracking Project', an ongoing interdisciplinary collaboration with Writtle University College and the dairy industry (funded by BBSRC and NERC); he also regularly publishes with Essex colleagues from Life Sciences and Psychology on topics including fisheries, plankton dynamics, coral reef systems, and human crowd behaviour. **Antonopoulos** regularly collaborates with psychologists at Essex on modelling of brain function. **Bao**, **Dai**, **Harrison** and **Lausen** all work with biologists and clinicians to develop statistical analysis methods within the field of genomics. Related research also crosses over into the fields of social sciences, with **Bao** and **Mahmoud** sharing a common interest in Genome-Wide Association Studies and the application of causal inference to health. Members of the Actuarial Sciences theme (**Fadina**, **Hu**, **Liu**, **Vrontos** and **Wong**) regularly collaborate with colleagues in the Essex Business School (EBS) and with economists, as well as external collaborators.

Organisation of meetings, workshops, and conferences

The department typically hosts two or three seminars each week: Data Science, Mathematics, and an additional specific seminar for PGR students. Early in 2020, the seminars were moved online and organised by **Mahmoud** and **Martinez-Garcia**, who is one of the two main organisers of the ZAG seminars, the first and largest online algebraic geometry seminar series (1,200 participants). The department also hosts regular **academic meetings and workshops**. DMS have been co-organisers of the EGL (Essex-Greenwich-London) annual conference on 'Algorithms and Applicable Mathematics' since 2012. DMS staff have also organised 'North British Semigroups and Applications Network' (2015); 'European conference on Data Analysis' (2015); 'Mathematical Ecology: Theory & Applications' (2016); Third Eastern ARC conference on 'Topological Solitons and Quantum Fluids' (2017); Meeting of the British Classification Society (2019); CoDiMa workshop 'Tools for Discrete Computational Mathematics' (2020); 'Trends and directions of Approximate Dynamic Programming: solving the curse of dimensionality' (2015). Several further events organised by DMS staff were funded but delayed by the COVID-19 pandemic including 'Mathematics of the Eastern Arc conference series', a two-day meeting on 'Integrability and Analysis of PDEs', a workshop on 'Algebraic Geometry and Geometric Invariant Theory Days', 3rd

IMA conference on Discrete Mathematics (taking place 2022).

DMS staff also play central roles in organising **national and international conferences** outside of Essex: 13 staff have been on organising committees (or equivalent) for over 35 international conferences in the mathematical sciences over this REF period. DMS staff have also developed a range of training opportunities for **UK and international PGR students**: **Akman**: Graduate students conference on 'Geometric and Harmonic Analysis' (Connecticut, 2019); **Antonopoulos**: Essex PhD summer school and *Proficio* courses: 'Modelling and Analysis of Complex Systems' (2016, 2017, 2018) and 'Mathematics for Researchers' (2018, 2019); **Codling**: organiser of 'META training workshop: Mathematical Modelling in Movement Ecology', Essex (2016); **Fadina**: co-organiser of the 'First Research School in Financial Mathematics', Nigeria (2018); **Harrison**: co-chair of the Research Data Alliance/CODATA Summer Schools in Data Science and Cloud Computing in the Developing World Working Group which led to the CODATA-RDA schools in Research Data Science (2016 onwards). The schools have been described as 'best practice' by the OECD; **Papamikos**: co-organiser of 1st Early Career South East Mathematical Physics Seminar, Kent (2014); **Vrontos**: short courses in 'Time Series and Forecasting in R' (2018) and 'Financial Modelling in Matlab' (2017) for PhD students and practitioners.

b) Indications of wider influence and recognition

Leadership within the discipline

Lausen is a past president of the International Federation of Classification Societies (IFCS) (2020-2021; president 2018-2019, president elect 2016-2017), a former president of the Data Science Society (GfKl) (2013-2019, vice-president 1995-2001, 2004-2013) and the founding vice-president of European Association for Data Science (EuADS) 2015-2018. **Susanto** is an elected member of the 'World Class Professors' programme (among only c.40 members from Indonesian academicians working abroad) by the Ministry of Research, Technology, and Higher Education, Indonesia since 2016. **Penman** is editor of the British Combinatorial Bulletin and Newsletter.

Elected Fellowships

Codling and **Higgins** are elected Fellows of the Institute of Mathematics and its Applications (FIMA); **Antonopoulos** is an elected member (MIMA). **Codling** is also an elected Fellow of the Royal Society of Biology (FRSB), and was an Invited Fellow at the Isaac Newton Institute in Cambridge (Stochastic Dynamics in Biology Programme, 2016). **Litterick** is a Humboldt Fellow.

Keynote talks

DMS staff have accepted invitations for plenary and conference talks at over 100 national and international conferences during this period. Selected international keynote talks include **Codling** (International Society for Applied Ethology, Vitoria, Spain, 2014; Models in Population Dynamics & Ecology, Torino, Italy, 2014; 39th Annual Larval Fish conference, Vienna, Austria, 2015), **Harrison** (Biological Big Bytes, Nanning, China, 2015), **Lausen** (ECDA2017, Wroclaw, Poland; 60th conference of the South African Statistical Association, Johannesburg, South Africa, 2018; IFCS2019, Thessaloniki, Greece) and **Martinez-Garcia** ('Positivity in algebraic and complex geometry', International Centre for the Mathematical Sciences, UK, 2017). DMS staff have also given over 120 research seminars at Universities around the world since 2014.

Editorial positions

Journal editorial roles within DMS include: **Antonopoulos**: Guest associate editor (AE) in *Biophysics, Frontiers in Physics*, AE for *International Transactions on Data Science, Engineering and Technology*; **Codling**: AE for *Movement Ecology*, *Methods in Ecology and Evolution*, and *Ecological Complexity*; guest specialist subject editor for *Ecological Applications*; **Grahovski**: guest editor for *Application of Mathematics in Technical and Natural Sciences – IX*, *AIP conference proceedings 1895* (2017); **Harrison**: editorial boards for *Briefings in Bioinformatics* (including

Special Issue on COVID-19), *BMC Bioinformatics*, *CODATA Data Science Journal*, *Journal of Integrative Bioinformatics*; **Lausen**: editor of the *Archives of Data Science Series A*, AE of *Behaviormetrika*, member of editorial board of *Advances Data Analysis and Classification (ADAC)* and *Methods of Information in Medicine*; **Meng**: *Complexity*; **Susanto**: editor for *Optical and Quantum Electronics*, *Communication in Biomathematical Sciences*, editorial advisory board for *Sustinere*, and *Indonesian Journal of Science and Technology*; **Williams**: *Cogent Mathematics and Statistics*.

Grant panels

Codling is a NERC Peer Review College member (typically attending one grant panel per year). **Harrison** has been part of BBSRC grant panel C (2014), BBSRC 'Tools and Resources Development Fund 2' (2014), and the German Federal Ministry of Education of Research (BMBF) 'e:Bio 3' (2015). **Grahovski** sat on an EPSRC Fellowship interview panel (2020).

Advisory boards and committees

Harrison is on the Advisory board for Nottingham Arabidopsis Stock Centre and **Penman** is a member of the British Combinatorial Committee.

Refereeing activities

DMS staff review for international research funders including Austria (Science Fund FWF), Bulgaria (Science Foundation), Chile (FONDEYCT), European Commission, Finland (Academy of Science), Germany (BMFT and DFG), Human Frontier Science Program, Ireland (Research Council for Science, Engineering and Technology, IRCSET), Netherlands (Organisation for Scientific Research, NWO), Russia (Science Foundation), South Africa (National Research Foundation), Turkey (Scientific and Technological Research Council of TUBITAK), and US (National Oceanic and Atmospheric Administration). DMS staff also review for UK funders, including BBSRC, EPSRC, ESRC, Leverhulme Trust, MRC, NERC, NIHR, Royal Society, plus the International Centre for Mathematical Sciences.

DMS staff review for over 130 journals, including *European Journal of Operational Research*, *Inventiones Mathematicae*, *Journal of the American Statistical Society*, *Journal Physics A*, *Memoirs of the AMS*, *PLoS Computational Biology*, *Sbornik Mathematics*, *Scandinavian Actuarial Journal*, *SIAM Journal of Scientific Computing*, as well as the AMS's *Mathematical Reviews* and the European Mathematical Society's *Zentrallblatt Math*.

c) Engagement with research users and beneficiaries

Engagement with industry and research users has been a key priority of the department over the REF period (**Objective 4**). **Codling** collaborates and regularly publishes with **CEFAS** (Centre for Environment, Fisheries and Aquaculture Science, Lowestoft), with **Omnisense Ltd** (Cambridge) and with the wider dairy industry in the ongoing Cow Tracking Project (BBSRC, 2012-16, and NERC, 2017-18). 'Project Beeswax' is an ongoing collaboration between **Salhi** and Simul Systems (Wickford, Essex), using operational research approaches to optimise the placement of beehives in commercial orchards. Salhi has also led a KTP with the Port of Felixstowe (**Hutchinson Ports**), addressing the problem of labour scheduling, and with **MSXi**, developing a predictive, self-learning model for automotive warranty expenditure. **Hadjiantoni** and **Gutierrez-Roig** have recently been awarded a KTP with the estate agent **Strike**, which will develop an AI-driven recommender system that fuses heterogeneous data streams and utilises knowledge graphs as well as other machine-learning methods. Since 2014, **Lausen** has led successful and ongoing KTPs with **Profusion** and **Mondaq**, using optimal tree ensembles (OTE) and other statistical learning methods to help develop their business models. **Yang** is also leading a KTP project with **Ocado**, which addressed issues of green distribution and optimum routing to reduce emissions in last mile delivery. DMS staff also received funding from HEFCE for the Catalyst Project, a collaboration with **Essex County Council**, **Suffolk County Council**, and **Essex Police** to develop new statistical

approaches to deliver improved public services. These research activities have motived new methodology research topics in both mathematics and data science.

d) Contribution to wider society and public

DMS has developed an active research outreach programme including visits to local schools, careers fairs, and public engagement events (typically 20-30 visits each year, reaching hundreds of students, teachers and members of the public), including an annual schools 'Winsten' day (supported by an endowment from former DMS Professor Chris Winsten), and regular attendance at local 'Café Scientifique' and 'Pint of Science' evenings. Four DMS staff are STEM ambassadors (**Bailey**, **Claridge**, **Codling**, **Litterick**), co-organising and running a series of Mathematics Masterclasses for local schools with the Royal Institution of Great Britain since 2019, and presenting on mathematics research topics at the local 'Big Bang at Essex' fair (annually since 2015). From 2014-15, **Codling** was invited to become BBSRC 'Schools Regional Champion' for the East of England, and undertook a range of interactive activities that demonstrated the importance of mathematics within life sciences research. This included a popular 'Maths of Cows' exhibit presented at the National Big Bang fair (NEC, Birmingham, 2014, at the invitation of the IMA, and in 2015), at the 'IMA@50 Festival of Mathematics and its Applications' (Manchester, 2014), at the 'What's Your Angle?' London Mathematical Society anniversary event (London Science Museum, 2015), and at various other national and regional events. **Codling** also has a long-running collaboration with the London Science Museum, undertaking a 5-week 'Live Science' residency in 2014 and a 'Halloween Lates' event in 2019, that used emergency evacuation and 'Zombie Horde' interactive experiments to explain the mathematics behind human crowd behaviour. Further engagement work in this period includes 'Science on Film' at the Francis Crick Institute (2019) and 'SET for Britain' at the Houses of Parliament (2014).

Higgins (winner of the Premio Peano prize in Italy in 2013) has published eight popular science books, including 'Very Short Introductions to Algebra' and 'Professor Higgins's Problem Collection' (published by OUP in 2015 and 2017 respectively). He was invited to give the *London Mathematical Society Popular Lecture Series* in 2019 and writes a regular column in the *Australian Mathematical Gazette*. **Vernitski** published an influential mathematics education study on growth mindsets of learners which produced a flurry of activity in social networks; these findings were subsequently popularised in articles in *The Conversation*, and have now reached more than a hundred thousand readers. **Susanto** wrote a popular science book titled *Tuhan Pasti Ahli Matematika* ('God Must be an Expert in Maths'), published in Indonesia in 2015; the book sold-out and featured extensively in national social media. He has also featured in several newspapers and magazines for his mathematical engagement activities (*The Jakarta Post*, 2017; *Hidayatullah*, 2017; *Koran Tempo*, 2018). He was one of only three invited speakers at the national *Science Communication* seminars (2017) with the topic 'Building a Science-based Society' by the Ministry of Research, Technology, and Higher Education, Indonesia, which featured on multiple news media. More recently, he has appeared in several television news items in Indonesia, talking about COVID epidemic modelling. **Codling** appeared on *Duck Quacks Don't Echo* (Sky One, UK, 2016) to discuss collective decision-making and the 'wisdom of crowds', and in the documentary *Human and Disaster* (KBS1, South Korea, 2014) to discuss the mechanisms behind human crowd behaviour in emergency situations.