Institution: London Metropolitan University

Unit of Assessment: 10 Mathematical Sciences

1. Unit context and structure, research and impact strategy

Unit context and structure

Research in our small Mathematical Sciences Unit of Assessment is carried out within STORM, the Statistics, Operational Research and Mathematics Research Centre (established in 1992). STORM lies within the Mathematical Sciences Group (MSG) of the School of Computing & Digital Media (SCDM).

STORM comprises four research active members of staff, Professor E. **Kissin** (Director of STORM), Professor R. **Rigby**, Professor M. **Stasinopoulos**, and Dr Z. **Hou**. Their research lies in many different interdisciplinary areas of Mathematics.

Kissin specialises in the theory of Operator algebras, Invariant Subspace theory and the theory of Algebra and Group Representations in Hilbert and Banach spaces and in the spaces with indefinite metric (Krein and Ponrjagin spaces).

Hou works in the field of Ordinary Differential Equations and Dynamical Systems. He is also involved in interdisciplinary research in the area of Mathematical Biology: theoretical biology and many population dynamics.

Professors Rigby and Stasinopoulos have been conducting collaborative research in Statistical Modelling and software development over several REF cycles. They developed one of the most widely used statistical modelling techniques in the world: Generalized Additive Models for Location, Scale and Shape (GAMLSS). The GAMLSS models, methodology and software have been used worldwide in many different scientific fields such as actuarial science, biology, biosciences, energy economics, genomics, finance, fisheries, food consumption, growth curves estimation, marine research, medicine, meteorology, rainfall, vaccines, etc.

STORM complements the extensive teaching programme of the MSG, where there are a number of other staff teaching mathematics and statistics and carrying out pedagogic research and other activities.

We are a small group, but our reach is wide. We have several international collaborations, and we are often approached by those who wish to work and study with us, including international scholars and students who wish to share our intellectual interactions. Consequently, STORM has dedicated office space with spare capacity for visiting researchers.

Strategic aims for research and impact during the assessment period

Our strategy for research and impact over the assessment period was described in our REF2014 submission. In 2014 we committed ourselves to:

1) carry out high quality research and disseminate the research through publications in high quality journals, published books, delivering invited international short courses and invited keynote international talks, and presenting research papers at international conferences (with papers published in conference proceedings),

2) increase our recruitment of PhD students and to integrate them more fully into the research culture of the group,

3) expand our extensive international research collaboration and further develop collaboration with users leading to increased impact,

4) contribute to the larger scientific community through membership of editorial boards, refereeing academic publications and refereeing research proposals.

Achievement of strategic aims for research and impact during the assessment period

Evidence of the achievement of the above strategic aims is given below:

1) 28 papers published in refereed journals,

Two books published,

Seven invited international short courses delivered,

Three invited keynote international talks given,

Seven articles published in international conference Proceedings,

Two external PhD examinations undertaken.

2) Five PhD students successfully completed (an increase of one).

Three PhD students registered at universities outside the UK, (from Brazil and Italy) visited STORM each for between 4 and12 months).

3) STORM's established, excellent international research reputation, and extensive international research collaboration and durable impact is clear. This is evinced clearly in the wide-ranging usage of the work described in, among other places, our Impact Case Studies.

Specifically, in terms of research outputs, our international research is well-evidence:

Thirteen of the 28 journal papers, and the two books mentioned in 1) above were results of international collaborations with researchers who are resident outside the UK, in many different countries, including Australia, Azerbaijan, Brazil, Italy, Japan, Netherlands, Portugal, Russia and Spain.

Seven of the 28 journal papers were interdisciplinary, with publications in journals including *The Bulletin of the World health Organization, Statistical Methods in Medical research, Journal of Sports Sciences, Energy Policy, American Journal of Human Biology and Food Microbiology.*

All seven published conference articles in 1) were produced with international collaborations with researchers who are resident outside the UK in several different countries.

The research centre STORM received many international visitors including:

One post-doctoral researcher for 5 months (from Italy) who collaborated on research on centile estimation, and four academics from Australia, Brazil, Netherlands and Russia (for up to a week). During their visits, current collaborative projects were discussed that resulted later in publishing two books and several of the papers mentioned above, as well as plans for future collaboration were considered. These are significant numbers in relation to our small size.

4) Two researchers in STORM are members of Editorial Boards of Mathematical Journals.

Researchers in STORM have refereed 52 papers for international journals, refereed one book and refereed one research grant proposal.

They also published numerous reviews for Mathematical Reviews and Zentralblatt Mathematics.

Members of STORM have developed and managed substantial software (specifically they manage 10 packages in the R CRAN library).

Members of STORM manage a website (www.gamlss.com) with, for example, over 13,000 hits in 2019.

Internally, as a part of the Mathematics Team, the members of STORM won the London Metropolitan University VC Award for 2018.

Impact during the assessment period.

Our approach to achieving impact has been to disseminate our research activity through activities listed in 1) above, together with providing substantial and very general applied software for statistical modelling and data analysis (the GAMLSS packages in R), maintaining a website (www.gamlss.com) to provide information and assistance in the application of the GAMLSS methodology and software, and providing advice to practitioners through meetings, emails and skype.

For example in our 'Centile and Growth Curves Estimation' impact case study, the impact resulting from the World Health Organisation (WHO) Child Growth Charts followed a 3 day visit by members of STORM to WHO in Geneva to explain the GAMLSS methodology and demonstrate the use of the GAMLSS software, followed by around 100 email exchanges. Similarly, the impact resulting from the INTERGROWTH-21st Project International Standards for newborn weight, length and head circumference followed from the attendance of a key researcher at our GAMLSS short course in Rotterdam, followed by subsequent emails.

Strategic aims for research and impact during the next five years

STORM plans to continue and expand the activities in areas 1), 2), 3) and 4) above.

The University has developed an effective policy to further stimulate research in STORM by attracting high quality researchers and by offering support to members of staff who have not yet been strongly involved in research.

The medium-term aim of STORM is to

1) continue and expand the high quality research;

2) expand our extensive research collaboration with colleagues in the UK and abroad and expand our collaboration with users, particularly in the area of statistical modelling;

3) disseminate our research through publication in the high-quality journals, participation in international conferences, giving talks at UK Universities and abroad and also through short courses in the UK and abroad;

4) continue and expand our contribution to the larger scientific community and take part in various professional activities such as organizing and participating in workshops and conferences;

5) participate in peer review, scientific committees and Editorial Boards of Mathematics Journals;

6) continue to recruit PhD students, provide them with a good environment and ensure timely completion;

7) to attract and employ high quality researchers in order to maintain our core strengths;

8) bid for funding to attract and recruit PhD students and post-doctoral researchers, and provide staff development leave for the existing staff;

9) develop current and new relationships with practitioners, especially in the application of Statistical Modelling to produce impactful practical applications.

2. People

Staffing strategy and staff development

STORM is a research centre within the Mathematical Sciences Group (MSG) of the School of Computing & Digital Media (SCDM). Currently STORM has 1.9 FTE staff.

SCDM has a well-established and inclusive staffing strategy and staff development in place. With regards to staffing strategy, since REF2014, STORM has recruited one research orientated academic staff member and endeavors to recruit further research active staff to consolidate our research activities.

In addition to STORM staff with an established research track record, the unit encourages other staff within MSG to engage in research and to produce high quality and impactful research. During the assessment period one member of MSG has successfully completed his PhD (Dr Getachew Zergaw) and another member who completed her PhD in 2012 (Dr J. Gill) is working on a series papers linked to her thesis. We wish to grow our FTE numbers who are active in research, which is line with the University's strategic mission.

The School offers a variety of supporting mechanism for researchers. We have a mentoring scheme; we provided workloads for research; we have a sabbatical scheme, which has benefited several colleagues per year; and we provided financial support for colleagues' research both locally and through two university-level schemes.. Our excellent parental leave policy (providing leave entitlement to both fathers and mothers) and a carefully managed return to work process has been established.

The School adopts a balanced approach (in terms of gender and ethnicity) in the composition of panels for appointments. Unconscious bias training is provided. When we make new appointments are assigned senior staff members with related research as mentors, quickly incorporating new staff into the SCDM research culture. The unit has mentoring systems and Professors regularly mentor Early Career Researchers (ECR).

SCDM has a well-established mechanism for promoting staff and monitoring staff development via our annual staff appraisal system.

In the REF period within UoA-10, Professor Robert Rigby has advanced from being a Reader to Professor.

During the appraisal, staff development is identified, and appropriate tasks are considered as deliverable targets. Researchers are given time, between 20% and 40%, for research related activities. When the University also gives sabbatical leaves to the researchers to focus on their research, their teaching and other duties are covered collegially by other members of staff and by HPLs (hourly-paid staff).

The unit is part of the School's Industrial Liaison Group where industrial research and secondment to industry is identified and brought to the attention of line managers

and Directors of research centres for approval.

Staff are regularly funded by the School to attend research conferences and workshops.

Members of the school frequently collaborate with each other on research bids and on research papers. Teams, typically made up of researchers at every stage of their careers, interact energetically throughout the processes of planning, applying for, and undertaking projects. Research bids are read and critiqued by other research staff before submitting them, allowing researchers to learn about each other's research.

Support mechanisms:

The University's Research & Postgraduate Office (RPO) provides support and training to both research active staff & students. RPO brings together postgraduate research students, academic staff, and others, across the University to make academic life as a postgraduate research student as smooth as possible. This includes academic support for students at every stage,–advising prospective applicants, and giving PGR students a platform to give feedback and contribute to the student journey. Staff training includes supervisory training, and sessions on chairing the PhD viva. RPO delivers PGR student training sessions designed to help research students negotiate the different phases of study and the varying challenges each phase presents. The RPO plays a key part in supporting PGR students and research staff in a variety of ways including induction, drop-in sessions, training on research philosophy, critical review of the literature, writing a successful research bids, research ethics and research project management.

RPO has formed a postgraduate research society (PGRS) whose general aim is to build a research community thereby enabling research students from different Schools within the University to work together. Through the PGRS, research students can:

(i) Connect with like-minded people for mutual support and peer support.

(ii) Socialize with others through social events, academic seminars and meet-ups outside University.

(iii) Promote and develop a research community from all backgrounds and studies.

(iv) Meet to develop research ideas among peers and create network opportunities.

(v) Attend activities aiming at developing research skills.

All research active members of staff, whether experienced or early career researchers are also given opportunities for a sabbatical period on a regular basis

(currently 6 months leave every 3 years). Their teaching loads are covered by other members of staff and by HPLs. Furthermore, research members of staff are encouraged to attend conferences, workshops and short courses to enhance their research knowledge and skills.

Training and supervision of postgraduate research (PGR) students:

PhD students are an integral part of our research strategy, playing an active part in research activities from writing papers to presenting at the SCDM research seminars, as well as presenting papers at international conferences. All students have 2 supervisors.

a Director of Studies (DoS) and a second supervisor. They have a room with desk, IT facilities, an extensive library, and good access to online resources.

As part of a strategy for transferable skills training, we provide students with opportunities to learn skills, which may help in the achievement of personal and career development goals. Research students are expected to discuss their training needs with their supervisory team and identify which activities are appropriate/necessary for their research and personal and career development.

The University wide Researcher Development Programme provides a range of training and development opportunities for PGR students. The courses are designed to support researchers in developing a full range of transferable professional, personal, research, and career skills and knowledge. The Programme offers a range of courses in four domains:

(i) Knowledge and Intellectual Abilities – the knowledge, intellectual abilities and techniques needed to carry out research.

(ii) Personal Effectiveness – the personal qualities, and career and self-management skills needed to take ownership of and engage in professional development.

(iii) Research Governance and Organization – the knowledge of the standards, requirements and professional conduct needed for the effective management of research; and,

(iv) Engagement, Influence and Impact – the knowledge, understanding & skills needed to engage with, influence and impact on the academic, social, cultural, economic and broader context.

We encourage our students to make full use of these programmes of training and support.

Information on progress monitoring:

SCDM and STORM operate a rigorous progress monitoring mechanism for PGR students, involving detailed 6-monthly progress reports and an annual review at Research Student Progress Group (RSPG) meetings in which a panel consisting of research supervisors and Directors of Research Centres & Groups advise on research progress and subsequent progression.

The Schools provide funds to enable all PGR students to attend international conferences during their studies on the condition they have published an output.

Once annually PGR students are expected to present a poster on their work at the annual Research and Enterprise Day. Effective interaction between PGR students and staff in the School is promoted through regular seminars and social events. External speakers participate in the School's Research Seminar Series, which raises awareness of key research developments and helps to encourage interdisciplinarity.

First year PGR students receive an induction programme including general and specific taught courses mentioned above, and targeted Health and Safety training. Students are required to complete a post-registration progress review form twice annually. This includes: description of the progress they have made on their research project since the last report to the RSPG; identify any challenges or problems encountered for which additional support, training or guidance might be required; and, an updated outline of their anticipated timetable for completing the research. Supervisors are required to comment on the student's progress in respect of their

programme of research. An independent reader also comments on the student's progress. As part of their training research students are expected to present their research at conferences and symposia. During the assessment period the STORM PhD students have presented their work at various international venues.

Supporting Equality, Diversity and Inclusion:

SCDM and STORM operate within University policies and procedures for equality, diversity and inclusion. The University disseminates policy and good practice in relation to both staff and students. It provides training and advice on interpretation and implementation of policies and codes of practice. The University's Equality, Diversity & Inclusion addresses gender, marital status, age, race, religious belief, political belief, disability, sexual orientation, and responsibility for dependents. The University is preparing application for bronze status of the Athena Swan Charter to promote equality for women in STEM subjects. The University has entered the Stonewall Diversity Champion programme and have joined Stonewall's Workplace Equality Index process, to assist us in implementing LGBT+ inclusive policies and practices across the University. The University is taking part in the government's Disability Confident scheme as a Disability Confident Committed employer and have published information to help and support our staff and our managers. SCDM supports equality of opportunity through open communications to staff about strategic initiatives, funding opportunities and training.

SCDM is supportive of the family and personal obligations of all members of staff, such as parents of young children. We allow people with caring responsibilities flexible working conditions, protecting them from teaching and other duties that require University attendance in especially pressured times. This is partly enabled by a culture that supports and encourages staff members to share work collaboratively with colleagues.

3. Income, infrastructure and facilities

Staff of STORM contribute to the teaching programme of the Mathematical Sciences Group and receive a significant time allocation (20% to 40%) for research, consultancy and staff development. Income earned from the REF 2014 helped to provide funding for teaching relief for members of STORM. There is dedicated office space for STORM members, with spare desk capacity for visiting researchers. STORM has modern computing facilities, with fast printing and copying facilities. The University provides excellent library facilities with a well-established series of 'traditional' journals and receptive to the acquisition of new journals and research texts. Online journal access is also available through the library's system. Research students have a dedicated office room with their own desk and PC.

The university central services provide dedicated staff to support the general-purpose computer science labs, networks and standard software builds for computers.

A large suite of software products is available for research using state-of-art tools.

The Research Office and a Finance Officer provide administrative support for the School in terms of preparing, costing and submitting research funding bids.

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

Despite being a small research centre, STORM has made substantial contributions to and collaborations with the research base and the practitioner base world-wide, resulting in significant impact. STORM plans to continue and enhance this over the coming years.

Specific contributions are given below.

Statistical Modelling

Professor R. Rigby and Professor D. Stasinopoulos

Professors Rigby and Stasinopoulos have a long record of collaborative research in statistical modelling and software development. They have developed what is now one of the most widely used statistical modelling techniques in the world, namely Generalized Additive Models for Location, Scale and Shape (GAMLSS). In 2014 their GAMLSS read paper to the Royal Statistical Society was one of the most downloaded papers of the Royal Statistical Society's publications and has over 1700 citations (in Google Scholar) to date. Their two published books on GAMLSS, provide the detailed theory, methodology and practical application (using their R software) of GAMLSS, to help both researchers and practitioners and expand the impact of GAMLSS. Their GAMLSS software comprises 12 packages in R (10 of which they manage). During the assessment period Professors Rigby and Stasinopoulos have published 13 papers in refereed journals, and also refereed 7 journal papers and one research grant proposal and supervised 3 successful PhD students.

The GAMLSS models, methodology and software have been used in many different scientific fields such as actuarial science, biology, biosciences, energy economics, genomics, finance, fisheries, food consumption, growth curves estimation, marine research, medicine, meteorology, rainfall, vaccines, etc. For example, the GAMLSS methodology and software were adopted by the Department of Nutrition for Health and Development of the World Health Organization for the construction of the worldwide standard growth (centile) curves for children.

During the assessment period, Professors Rigby and Stasinopoulos have further developed a lively international environment in STORM by:

1) hosting international visitors (for periods from 1 day to 1 year),
2) giving international invited short courses, keynote talks at conferences, and presenting papers at conferences,
3) maintaining a dedicated GAMLSS website (www.gamlss.com) with world-wide hits,
4) maintaining 10 GAMLSS R packages in the R CRAN library,
5) providing world-wide on-line consultancy on the GAMLSS methodology and GAMLSS R software,
6) publishing two books, in collaboration with researchers who are resident outside the UK, and publishing 13 papers in refereed journals, of which 9 are in collaboration with researchers resident outside the UK.

Details of the above activities **(during the assessment period)** are given below:

1) Professors Rigby and Stasinopoulos have hosted many international visitors including: 3 PhD students registered at universities outside the UK (Dr Luiz Nakamura, Dr Fernanda De Bastiani, both from Brazil, and Dr Andrea Marletta from Italy, each staying between four and twelve months), and hosted one post-doctoral researcher (Dr Marco Enea from Italy staying five months), and two academics (Professor Gillian Heller from Australia and Professor Paul Eilers from the Netherlands, each staying several days).
2) Professor Stasinopoulos has given seven international invited short courses on GAMLSS around the world (in Austria, Columbia, Italy, Netherlands and Spain), and 2 international invited keynote talks at conferences (in Austria and Columbia). Professors Rigby and Stasinopoulos have published six papers in international conference proceeding (in Austria, Brazil, France, Germany and Spain).
3) The dedicated GAMLSS website (www.gamlss.org), managed by Professor Stasinopoulos, has been active throughout the assessment period receiving multiple world-wide hits. For example, during 2019, the website received 14,639 hits from 9,987 different users from 123 different countries, of which 22% were from the USA, 14.1% from Brazil, 10.0% from the UK, 6.1% from Germany, 5.5% from China, 3.3% from Japan, and the remaining 39% from the other 117 countries.
4) The GAMLSS software of Professors Stasinopoulos and Rigby now comprises 12 R packages (of which 10 are managed by Professor Stasinopoulos) in CRAN, the R software library. For example, their main R package is called GAMLSS.
5) Professors Rigby and Stasinopoulos have provided world-wide consultancy on their GAMLSS models, methodology and software throughout the assessment period (by email, skype, etc.).
6) Professors Rigby and Stasinopoulos published 2 books on GAMLSS, in collaboration with researchers resident in Australia and Brazil. They also published 13 papers in refereed journals, of which 9 are in collaboration with researchers resident outside the UK.

For example, they collaborated with Professor Van Buuren, (University of Utrecht, The Netherlands), and Dr D. J. Hayes, Dr F. O. Ter Keile and Dr D. J. Terlouw (Liverpool School of Tropical Medicine, Liverpool, UK), on optimizing age-based dosing of antimalarial drugs, and with Dr Vlasios Voudouris (Chief Data Officer, Argus Media, UK) and Dr Matsumoto (Kyoto University, Japan) on natural gas production.

Professor Stasinopoulos has also collaborated on interdisciplinary research in nutrition health, biology and sport science, resulting in four papers published in refereed journals.

Pure Mathematics

Professor E. Kissin

Edward **Kissin** specializes in the field of Operator theory, the theory of Banach and C*-algebras, invariant subspace theory and the theory of algebra and group representations. He works closely with Professor Victor Shulman (Russia), who is a former full-time member of STORM, and with Professor Yuri Turovski (Azerbaijan).

During the assessment period, **Kissin** has published 6 papers in refereed journals, of which four were international collaborations with researchers resident outside the UK. Two more joint papers are accepted for publication.

In a joint paper with his PhD student T. Formisano, **Kissin** investigated the structure of Lp-spaces of operators between Schatten ideals and obtained some analogues of

Clarkson-McCarthy inequalities for these spaces.

In a series of collaborative papers **Kissin** and Professor Shulman (Russia) investigated non-unitary representations of nilpotent groups, their groups of cohomologies and neutral cohomology cocycles. They applied these results to the study of the decomposition of the extensions of representations of nilpotent groups. This approach, in turn, led to the further development of the theory of *J*-unitary representations of nilpotent groups on the spaces with indefinite metric which is widely used in Quantum mechanics. They are now working on the extension of these results to connected groups with connected normal Engel subgroups.

Together with his collaborates: Professor V. Shulman (Russia) and Professor Yu. Turovski (Azerbaijan), **Kissin** worked on the development of some new approach to abstract lattice theory that allowed them to apply its tools and the results to various problems of Operator Theory, the theory of Banach algebras and to the structural analysis of C*-algebras. In particular, they used it to characterize the structure of the lattices of two-sided ideals in C*-algebras, their largest GCR-ideals, the largest nuclear ideals, AF-ideals and exact ideals in terms of the radicals of certain relations in these lattices.

Using this lattice theory approach further, **Kissin** obtained a full description of special type relations and their radicals in the lattices of projections in W*-algebras.

A new radical approach has also been developed in a joint paper with V. Shulman and Yu. Turovskii to the joint spectral radius theory in Operator algebras.

In another paper they introduced various modifications and new methods in the proof of Pontryagin-Krein Theorem.

Since 2010, **Kissin** has been a member of Editorial Board of Eurasian Mathematical Journal.

He was an invited lecturer at Belfast conference on Harmonic Analysis and has given talks at various British Universities and abroad.

He acted as an external PhD examiner at Leeds University.

For the last three years **Kissin** has been the London Metropolitan University correspondent for Isaac Newton Institute of Mathematical Sciences (Cambridge).

He is a member of the professional network for scientists “Research Gate” with score 25.66 and has numerous reads and citations.

Professor Kissin hosted many international visitors including: Prof Yu. Turovskii (Azerbaijan), Professors V. Shulman and A. Helemskii (Russia), Professors V. Lomonosov and B. Simon (USA).

During the assessment period **Kissin** has been a peer review assessor of one book and of 28 articles submitted to leading mathematical journals such as Journal and Proceedings of the London Mathematical Society, Journal of Functional Analysis, Transactions of the American Mathematical Society, Indiana University Mathematical Journal, Proceedings of the Edinburgh Mathematical Society, among others.

For many years **Kissin** has also been refereeing numerous papers for Mathematical Reviews.

Z. Hou

Zhanyuan **Hou** specialises in the field of ordinary differential equations and (discrete and continuous) dynamical systems. During the assessment period, he has published 6

papers in refereed journals. He has also refereed 17 papers for journals.

In particular, he is interested in the area of Qualitative and Asymptotic Behaviour of solutions of some classes of ordinary and functional differential equations**. Hou's** work in this area involves theoretical analysis of behaviour of solutions of some class of differential equations with or without delays. This includes existence of a fixed point, local and global stability of a fixed point, a fixed point as a global attractor or a global repellor restricted to a certain manifold, vanishing components, periodic solutions, bifurcation, oscillation, limit cycles, and behaviour near limit cycles.

Hou also works in the area of Mathematical Biology and dynamical systems. In theoretic biology, many population dynamics are modelled mathematically by dynamical systems (discrete or continuous). Thus, effective investigation of species evolution relies on our knowledge about the solution behaviour of the model. Hou's research in this area is mainly on qualitative and asymptotic behaviour of some type of biological models, e.g. Lotka-Volterra and Kolmogorov systems, in response to prediction for long term future of the species coexistence or extinction.

Hou has been doing collaborative research since 2010 with Dr Stephen Baigent (UCL), who specializes in mathematical biology and dynamical systems. They have published a series of joint papers. This collaboration of research will continue in the immediate and longer term, to produce high quality outputs (and possible external funding). Dr Hou is also interested in discrete dynamical systems and has published some joint papers on difference equation with his PhD student S. Wu.

Since 2013 **Hou** has been a member of Editorial Board of the Journal of Mathematical Research and Applications. He has been refereeing articles for many academic journals (e.g., Theory in Biosciences, Acta Math Sci, Journal of Biological Dynamics, Communications on Pure and Applied Analysis, Journal of Applied Mathematics and Computing, Mathematical Bioscience, Nonlinear Analysis, Proceedings of American Math Soc, etc.) and contributing reviews for Mathematical Review and Zentralblatt Math.