**Institution:** University of Greenwich

**Unit of Assessment:** (UoA 10) - Mathematical Sciences

**a. Overview**

The Mathematics Department has 15.5FTEs of academic staff and is part of the much larger (100 academic FTEs) School of Computing and Mathematics Sciences (CMS). The UoA10 application is from a small group of staff within the Mathematics Department, active in the areas of Operational Research, Statistics and Computational Mathematics and making a distinctive contribution to these areas under the headings of Scheduling Theory, Stochastic Modelling and Numerical Mathematics and Algorithm Development. They are all academic members of the Mathematical Sciences Department and have membership either of the Statistics & Operational Research Group or the Numerical and Applied Mathematics Research Unit. Each of these groups has established fruitful external collaborations, has a history of successful bids for research grants and has a small but successful training programme of PhD and MSc (by research) students.

This is a growing department and recent new staff recruitment will underpin these research groups within the area of computational mathematics and in OR. A number of Department staff have been entered into other units of assessment, mainly UoA12. Of the remaining academic staff not submitted, three are professionally active in the area of Mathematics Teaching and Learning in Higher Education (including an HEA National Teaching Fellow), along with one who is in this UoA 10 submission. The department takes an active role in contributing to the development of research into Mathematics Education in HE.

**b. Research strategy**

After the relative success of RAE2008, it was clearly going to be productive for the Statistics and Operational Research Group (SORG), led by Prof Strusevich, to expand its methodological work in the area of Deterministic Machine Scheduling. Consequently one of the goals of the 2008-2013 period has been to build up a scheduling core within the SORG. This has been achieved, with Drs Alan Soper and Kabir Rustogi now actively conducting scheduling research, together with Professor Strusevich. The main areas of joint research include scheduling with changing times (Rustogi/Strusevich) and scheduling with transporters (Soper/Strusevich). International collaborations are part of the strategy and include Prof Kellerer (Graz, Austria) and Dr Shioura (Sendai, Japan) carried out with an active schedule of visits to a from Greenwich, supported by the Department and in part by EPSRC travel grants.

During this period Dr Ramesh has actively developed his research in the area of stochastic modelling into hydrology applications using a likelihood approach. A key area of development has been stochastic point process models for fine-scale rainfall. A planned development in this stochastic modelling work is to provide additional dependencies in Hidden Markov models and explore its application in the modelling of regional rainfall.

Prof Lai was submitted to the Computing assessment panel in RAE2008 but is now a part of U0A10 with a research direction more geared towards the development of numerical mathematics, techniques, and algorithms for scientific computing and with applications in important areas of applied mathematics. This prompted the building of the Numerical and Applied Mathematics Research Unit supported by a series of PhD students and research fellows. This strategy has resulted in collaborations to develop numerical methods for the optimisation of computational fluid dynamics design systems with Alstom UK Ltd., nonlinear problems in commodity markets with 9 other partners within a FP7 STRIKE project led by Prof. Ehrhardt, Wuppertal University, Germany, image denoise and dehaze with Prof. Wang, Fuzhou University (China), absorption and metabolism models with the Fourth People's Hospital, Wuxi, China, and mechano-sensation in cardiac cells with Prof. Knoell, Imperial College. The overall aim has been to align algorithm developments for scientific computing to various industrial applications and to encourage close links with local industry. Most notably, the TSB project OPTWELD (TSB/CRD/096 Q20688) http://www.optweld.org.uk/ has built a strong link between Greenwich and TWI Ltd and ESI Group, during 2008 to 2011, in the area of automating their computer design process (http://www.optweld.org.uk/home/optweld_overview.pdf) through the use of the techniques described in the Case Study. This followed on from earlier industrial application work with Fujitsu

Laboratories of European Ltd in 2004 in the application of domain decomposition methods.
In current and future work NAMU will build upon their expertise in numerical methods for domain decomposition and defect correction in applications to inverse problems, image processing, computational biology, and stochastic optimisation.

**c. People**

**i. Staffing strategy and staff development**

The University of Greenwich is a research informed institution, i.e. research has a prominent role in our staffing strategy, alongside high quality teaching. The staffing strategy for mathematics academic appointments values teaching capability in equal measure to research capability, and all new academic staff are expected to have a PhD. New academic staff are supported in their research through the Greenwich Early Career Researcher Network and a targeted competitive awards programme. There are approximately 1.5 FTE technical support staff dedicated to maintaining and enhancing the research hardware and software.

The University of Greenwich has a policy of encouraging staff development and providing facilities for staff at all grades. In terms of the Concordat, the university is fully compliant and seeks to ensure that the potential exists for research staff to have clear and well-defined career progression opportunities (http://bit.ly/18XahOG). To this end, staff development opportunities are made available to research staff alike, with training and development provided both within the University (http://bit.ly/177WBE3) and also externally within reasonable budget constraints. All staff have the opportunity at appraisal – and throughout the year – to raise development issues with line managers. The university also has procedures in place for equal opportunities and diversity (http://bit.ly/18X9VaV).

**ii. Research Students**

The University has a well-developed procedure for monitoring PhD research programmes, administered by campus Research Degrees Committees (RDC). There is also a PGT Tutor to monitor PhD student progress and provide pastoral care; each student is assigned two research supervisors. PhD students attend the appropriate MScs or other appropriate short courses as part of their studies. Presentation of their work in internal seminars develops their presentation skills in front of peers and supervisors, prior to making external presentations. A regular programme of invited external speakers enhances awareness of relevant research beyond the university. All PhD students have access to state-of-the-art computational and laboratory facilities supported by RCIF funds.

**d. Income, infrastructure and facilities**

**Research income**

Prof Strusevich's EPSRC grants were used strategically in buying out research time and travel costs for himself and overseas collaborators.

Prof Lai's 2012 London Mathematical Society Scheme 8 Grant (LMS 81106) was used to organise the EGH2012 Workshop on Applied and Numerical Mathematics for Multiscale Problems held in June 2012, http://ghsymposium.gre.ac.uk/EGH2012/, with a focus on building stronger links with industry.

Prof Lai's 2012 FP7 ITN AeroTraNet 2 (Ref 317142) grant funded an Aeronautical training network in aerodynamic noise from wide body civil aircraft. This involved a consortium of 9 partners in which Greenwich leads the work package on modelling and optimising computer based design processes for aerodynamic noise reduction (https://www2.le.ac.uk/projects/aerotranet/aerotranet2).

Prof Lai's 2012 FP7 ITN STRIKE (Ref 304617): Novel methods in computational finance involving a consortium of 10 partners in which Greenwich leads the work package on Newton-like methods for nonlinear problems in commodity markets (http://www.itn-strike.eu/).

Prof Lai's 2013 London Mathematical Society Scheme 1 Grant (LMS 11222): Support to organise the LMS minisymposium on 'Advanced decomposition methods for partial differential equations in September 2013. This is part of our strategy of fostering future collaboration with international partners.

Prof Lai recently successfully bid for a University Vice-Chancellor's PhD scholarship awarded for Inverse problems and applications in computational biology. (This is related to foster future collaboration with health organisations.)

**Infrastructure**
Annually, the University allocates a proportion of RAE income to established research groups that were successful in RAE2008 and allocates the remainder by competitive internal bidding. SORG and NAMU bid for RAE funding to underpin their main activities and supplement its research grant income. This funding is used to: support active researchers with travel and equipment, and provide bursaries for PhD students. RCIF funding has provided state-of-the-art research infrastructure. Within the School(s) there are also Directors of Research and Enterprise who both sit on the School Management Committee, bringing the research and enterprise agenda to the highest levels of School governance. The University recently introduced a number of PhD studentships which are awarded annually on a competitive basis. The Groups have won two of these over the past 2 years, since their inception.

Research infrastructure is continuously being renewed and enhanced. All research staff/students have their desk-top computers upgraded as part of a rolling programme. The School-based research network is continuously upgraded by the addition of equipment e.g.: 6 Tb SAN storage has been upgraded to 10TB this year, off-site backup/replication for maximum resilience of storage area, 1GB comms back-bone has been upgraded this year to 10GB, 1GB switches and dedicated research servers. Other facilities include a dedicated server room space in Dreadnought Library which has been enhanced to cater for HPC servers, two distributed memory high performance clusters, a 40 processor system and a high performance shared memory 64 processor Linux cluster, implementation of Virtual Desktop Environment and Virtualisation of servers enabling research groups the ability to demonstrate software to clients and development of their specialised software. Most recently, in 2013 a 20 node window cluster and 12 node GPU cluster was purchased to support parallel and distributed computing research. These provisions have been made available via RCIF expenditures of £802k since Jan 2008.

**Facilities**
Research staff have access to library facilities, video conferencing facilities, and secretarial support. Our researchers are all located in close proximity to each other providing an environment for cross fertilisation of ideas and knowledge between the groups in the centre. Each researcher has their own desk and a dedicated computer to undertake their work. This is also the case for PhD students.

**e. Collaboration and contribution to the discipline or research base**

**SORG - Collaborations**: The main research area of Professor Strusevich is in the methodological aspects of scheduling. During the period 2008-2013 he has published 32 papers on this subject in peer-reviewed journals, with 2 more accepted. The full list of his peer-reviewed publications can be found at http://staffweb.cms.gre.ac.uk/~sv02/publications, with the outlets including Operations Research, SIAM Journal of Discrete Mathematics, Journal of the Operational Research Society, European Journal of Operational Research, Omega and other highly regarded journals.

Among his main international collaborators are Prof Kellerer (Graz, Austria) and Dr Shioura (Sendai, Japan), who have visited Prof Strusevich at Greenwich on several occasions to collaborate on joint research. Prof Strusevich also paid several visits in return. These meetings and continued correspondence in between have resulted into successful project proposals. The team Strusevich/Kellerer have studied problems of quadratic Boolean programming with scheduling applications (EPSRC funded project EP/018441/1, 2011-2013). Problems of submodular optimisation with scheduling applications have been studied by the team Shakhlevich (Leeds), Strusevich/Shioura (EPSRC funded project EP/J019755/1, 2012-13).

Dr Ramesh has made regular research visits to Imperial College to develop his interdisciplinary collaborative research work on stochastic modelling in hydrology and environmental engineering.

Building on his earlier work in this area, he has established collaborative work with Dr C. Onof and his colleagues from the Environmental & Water Resources Engineering Section at Imperial College on the development of multi-site stochastic point process models. In addition he has worked together with Prof Anyue Chen (at Liverpool University) exploring weighted Markov branching processes.

**SORG – contributions to the discipline**: Prof Strusevich has co-authored several invited surveys (EJOR, 4OR, Journal of Scheduling), acted as a guest editor of 3 special volumes (Computers & OR, 2009; Journal of Scheduling, 2012; Annals of OR, 2013), and worked as an Associate Editor of Computers & OR and the Journal of Combinatorial Optimisation. Prof Strusevich has given several key-note presentations, including the 50th and the 55th conferences of the Operational Research Society. Since 2003, he has been teaching a course for MSc in Logistics, on Scheduling Models and Algorithms at Molde University College, Norway.

During 2008-2013 Professor Strusevich was a Guest Editor of three special volumes:
- Scheduling for Modern Manufacturing, Logistics, and Supply Chains. Computers & Operations Research, 2009, vol. 36, Issue 2.
- New Branches, Old Roots. Journal of Scheduling, 2012, vol. 15, No 4.
- Computational Issues in Combinatorial Optimization. Annals of Operational Research, 2013, vol. 207

During 2008-2013 Professor Strusevich has been an Associate editor for
- Computers & Operations Research (resigned in July 2013)
- Journal of Combinatorial Optimization

During 2008-2013 Professor Strusevich has given key-note talks at
- the 50th Conference of the Operational Research Society (Scheduling stream, York, 2008)
- The 9th Workshop Models and Algorithms for Scheduling and Planning (The Netherlands, 2009)
- the 55th Conference of the Operational Research Society (Optimisation stream, Exeter, 2013)

During 2008-2013 Professor Strusevich was a member of Programme Committees of the following Conferences
- International Conference on Computers and Industrial Engineering (CIE39), (France, 2009)
- Joint ECCO/CO conference (Spain, 2010)
- The 4th Conference on Combinatorial Optimization and Applications (COCOA), (USA, 2010)
- International Conferences “Tanaev’s Readings”, (Belarus 2010, 2012)
- International Symposium on Combinatorial Optimisation (Oxford, 2012)

Since 2010 Professor Strusevich has been an invited stream organiser (Scheduling) at the EURO Conferences (Portugal 2010, Lithuania 2012, Italy 2013).
Dr Ramesh has been a PhD external examiner – at University College London (2012), and at the University of Manchester (2013).

**SORG – Awards**:
The PhD Thesis of Kabir Rustogi (supervised by Prof Strusevich and Dr Ramesh) has been nominated for the PhD Prize established by the Operational Research Society.

**NAMU - contributions to the discipline**:
Prof Lai is actively engaged with a number professional societies: he is a Fellow of the IMA, Member of the LMS, Member of the EMS, and a Member of the British Computer Society. As a part of his services to professional societies he is on the IMA Membership Committee and Secretary to the BCS Distributed and Scalable Computing Specialist Group. Prof Lai is a Co-Director of the Fuzhou-Greenwich R&D Centre for Applied Computing, Fuzhou University, China – (with the goal of bringing numerical and scientific computing techniques into the computing sector in relation to image processing.)

Prof Lai is Co-Chair of the Steering Committee for DCABES (International Symposium on

Distributed Computing and Algorithms for Business, Engineering, and Sciences) - (fostering interdisciplinary activities that cross fertilise modern computing facilities with numerical mathematics and scientific computing.)

He was Workshop Chair of the EGH2012 Workshop on Applied and Numerical Mathematics for Multiscale Problems, Greenwich, June 2012 and Co-organiser of the International Workshop on Image Processing and Inverse Problems, Fuzhou, China, Dec 2013. He was also Symposium Chair of the LMS Mini-symposium on Advanced Decomposition Methods for Partial Differential Equations, Kingston, Sept 2013 (providing a meeting place for fostering collaboration between computer scientists, mathematicians and engineers.)

**Lai - Invited keynote lectures**:
On the use of gradients for image processing, July 2008, China Criminal Police University, Shenyang, China. On high order schemes and defect correction methods, December 2009, Second Belgian Mathematical Society and LMS Conference, Catholic University of Leuven.
On the defect correction method and its applications, March 2012, International Workshop on Computational Science and Numerical Analysis, The University of Electro-Communications, Japan.

**Lai - Journal editorship**:
Editor-in-Chief, International Journal of Computer Mathematics Section B.
Editor-in-Chief, Journal of Algorithms and Computational Technology.

Book series editor, Numerical Analysis and Scientific Computing, CRC Press.

**Lai - External examiners:**
PhD examiner – University of Hertfordshire (2008), Kingston University (2009),
University of Liverpool (2010), Claude Bernard University of Lyon (2011), University of Leeds (2013).

An active group of Mathematics Department staff are involved in research into the history of mathematics and in developments in HE mathematics teaching but are not submitted in this group. (Tony Mann, Noel-Anne Bradshaw, Nadarajah Ramesh (who is submitted to UoA10)). They have published extensively, been awarded substantial HEA grants and have presented regularly at the annual MSOR, HEA STEM conferences over the last 5 years. They are active professionally e.g. on the IMA Council, the British Society for the History of Mathematics, the Gresham Society, the Royal Statistical Society and the Operational Research Society. They include a National Teaching Fellow and winner of the THES Innovative Teacher of the year 2010.