Institution: University of Greenwich

Unit of Assessment: (UoA10) – Mathematical Sciences

a. Context

The UoA10 submission is from a group of staff within the Department of Mathematical Sciences which is part of the much larger (100 academic FTEs) School of Computing and Mathematics Sciences (CMS), 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. The staff are all members of the Statistics & Operational Research Group (SORG), or the Numerical & Applied Mathematics Research Unit (NAMU).

The areas of impact come from:

- the development of new methodological approaches to scheduling problems creating the potential for improvements in scheduling software;
- the application of novel stochastic models to rainfall modelling creating the potential for improved modelling accuracy;
- the novel development and application of numerical algorithms, improving software efficiency across a range of applications including engineering design.

The main user groups and beneficiaries are planners, hydraulic engineers and design engineers within industry, and policy makers and legislators.

b. Approach to impact

During the assessment period, the unit's approach has been through three main channels:

(i) Directly engaging industry users in project design

Prof. Lai organised a series of One Day Workshops on Applied and Numerical Mathematics (http://ghsymposium.gre.ac.uk/GH2010/, http://ghsymposium.gre.ac.uk/EGH2012/) and a London Mathematical Society(LMS) Minisymposium on Advanced Decomposition Methods for Partial Differential Equations (http://cms1.gre.ac.uk/conferences/LMS2013/index.html) with the intention of engaging industrial participants so that joint work could be identified and formulated. He has built relationships with the Institute of Food Science, Norwich, and Plextek Ltd, Cambridge, and maintained links with TWI Ltd, Cambridge, and the ESI Group, Rainham. As an outcome of a seminar presentation at the Dept of Engineering, University of Leicester in 2009, Prof. Lai established a productive link with Dr Aldo Rona that contributed to the building of the FP7 supported network AeroTraNet 2. This led to a new collaboration with Alstom on the optimisation of the design cycle using CFD software through the AeroTraNet 2 funding of £257,000 to Greenwich.

(ii) Stimulating and participating in knowledge transfer/exchange networks

In response to a call from Prof. Matthias Ehrhardt, Wuppertal University, Germany, on contributing a chapter to the book 'Nonlinear Models in Mathematical Finance: New Research Trends in Option Pricing', Prof. Lai wrote a chapter on 'Numerical solutions of certain nonlinear models for European options on a distributed computing environment'. As a result of this work Prof. Ehrhardt created a new network in computational finance of which Prof. Lai is now part. This network involves a number of companies from the finance sector and is supported by the FP7 project ITN STRIKE (Ref 304617). Prof. Lai will receive a total of £329,000 from FP7 to work on nonlinear problems in commodity markets. Prof. Lai is also a co-director of the Fuzhou-Greenwich Applied Computing R&D Centre based in Fuzhou University, China (http://cmcs.fzu.edu.cn/glwz/). Through this Centre Prof. Lai has been able to interact with companies in China, especially in the area of image

processing.

Dr Ramesh is an active participant in the PURE (Probability, Uncertainty and Risk in the Environment https://connect.innovateuk.org/web/pure#) Knowledge Exchange Network. His work on rainfall modelling in collaboration with Dr C. Onof and his colleagues from the Environmental & Water Resources Engineering Section at Imperial College has created a route for take-up by practising hydraulic engineers, hydrologists and climate modellers. This work is directly relevant to the water industry. These models can be used as reliable tools for flood design in a continuous simulation framework and also can be used to generate fine-scale rainfall input to be used in large-scale climate models.

(iii) Developing commercial interest in research through proof-of-concept projects

The development of these activities has been supported by the university's research and enterprise office (GRE), the CMS School Business Development Manager, and GRE-administered HEIF funding. Prof. Lai received GRE proof-of-concept funding of £13,128 in 2010 to develop the 'Greenwich Image Processing System' which is capable of recovering damaged images, in direct response to problems posed by industry contacts, and a second GRE proof-of-concept fund of £46,385 in 2012 to add to the system the capability of handling haze images. The prototype system is now being tested.

A pilot proposal for **low risk** flight schedules for deliveries and pickup of employees to/from off-shore installations in the oil and gas industry was developed by Prof. Strusevich and financially supported through university proof-of-concept funding in order that oil and gas industry representatives could be consulted over the feasibility of the project.

c. Strategy and plans

The primary target of the Numerical and Applied Mathematics Research Unit will be to develop a suite of "digital laboratory" applications in the areas of mechanical engineering, medical biology and image processing applications, providing long term and sustainable solutions to complement physical laboratory work.

Firstly the research investment fund described above on computational medical biology will be used to foster collaboration with Prof. Knöll, Imperial College, on a mathematical model of mechano-sensation of heart cells. The plan here is to publish initial results through a book chapter in Pflügers Archive European Journal of Physiology and to develop a major joint research proposal. This work will be used to support at least one researcher.

Secondly the Numerical and Applied Mathematics Research Unit will work on the development of modern techniques in inverse problems using the current funding and collaboration with Alstom. It is expected to develop this into an enterprise contract targeted at improving the design cycle for industrial products of Alstom. These techniques will also be directed to the modelling of absorption and metabolism of nutrients in collaboration with the Institute of Food Science, Norwich, and the UoG School of Science. The planned output is a joint research council funding proposal for a multiscale approach to modelling in food science.

Thirdly the Numerical and Applied Mathematics Research Unit will continue its effort in image processing work based on the current proof-of-concept fund on heat haze problems. The aim here is to enhance the current 'Greenwich Image System' for various socio-economic applications such as restoration of surveillance camera images and archaeological images in collaboration with local industry. The university has also agreed to set up a Greenwich Maths Centre which will support and promote both the two research groups and the Mathematics HE Pedagogy group and general outreach activities of the Department of Mathematical Sciences. The centre will have a Director

and Deputy Director and part time administrative support.

The Statistics & Operational Research Group is developing a proposal for a full-scale research project for a decision support system for creating **low risk** flight schedules for deliveries/pickup of employees to/from off-shore installations in the oil and gas industry. The group is working on identifying potential industrial partners who would collaborate and partly fund this project. Due to the novelty of the project topic, it is likely to result in several publications in high rank journals on logistics, transportation and general operational research, jointly written by the academic and non-academic partners. Since such a decision support system will capture the main features of helicopter operations in off-shore oil/gas industry, such a system could be sold or provided to various companies all over the world.

Dr Rustogi's contributions in the area of scheduling with changing times and maintenance have introduced novel generalised models, pointing out the drawbacks of prior research and improving the methodological toolkit. His thesis has been awarded the best PhD Prize of the Operational Research Society for 2013. These achievements have put SORG into a leading position in this area, and the group is preparing a proposal to setup an international research network that will further advance the area of scheduling with changing times. Colleagues from Poland, Israel, Japan and France are planning to participate.

Dr Ramesh's conference dissemination activities will continue, with typical audiences of hydrologists, engineers, rainfall modellers and statisticians (eg the 10th Precipitation Conference in Coimbra 2010). This is planned to expand to include regular engagement with the European Geophysical Union's annual assembly in Vienna.

d. Relationship to case studies

The case study of Prof. Lai describes applications of his research to local industry via collaborative projects. It provides examples of how an agile approach to opportunities combined with university support has contributed to successes in obtaining external and industrial funding and created opportunities to engage overseas industry.

The SORG Case study from Prof. Strusevich describes how the group supports methodological advances following through into applications, beginning with low-risk helicopter flight scheduling. This project is an early-stage collaboration between industry and academia suitable for wider communication to the general public.