Institution: University of Southampton

Unit of Assessment: 10 Mathematical Sciences

a. Context

Mathematics provides a framework for understanding the world in which we live. Mathematicians and Statisticians at Southampton engage in a broad spectrum of high quality research and are actively developing innovative applications with direct economic impact as well as broader impacts on health and welfare, environment and public policy. We undertake research across the full range of mathematics; Pure Mathematics, Applied Mathematics, Statistics and Operational Research (OR). We have a long and successful tradition of fostering and developing interdisciplinary links with a wide range of researchers and external end users and as a result the non-academic beneficiaries of our research are also wide ranging.

Our Pure mathematicians are increasingly engaging in interdisciplinary research with direct impact on society, through for example an improved understanding of the geometry of large and complicated datasets. In Applied Mathematics, our modelling group, which is well known for its expertise in applying mathematics to industrial problems through its contributions to the Study Groups for Industry worldwide, is developing a new and exciting focus on applications in biotechnology and medicine. Research in Statistics and Operational Research is focussed on developing new theory and methodology in combination with application driven research.

Our main user groups in the REF period are:

Government Agencies and NGOs: We have carried out statistical modelling for the *Office for National Statistics (ONS)* for the census, the *Meteorological Office* and the *US Environmental Protection Agency (USEPA)* to model air pollution and the *Animal Health and Veterinary Laboratories Agency* to model animal disease, optimisation of resources for the *NHS* and *Regional Health Authorities,* multi-objective optimisation in designing spacecraft for the *European Space Agency (ESA),* scheduling to reduce congestion for the *Rail Safety Standards Board* and encryption for *GCHQ/Heilbron Institute*.

Large Companies: We have a number of active links with large companies. These include*; Jaguar, Ford, GSK* and *Corning* where we use mathematical and statistical modelling to improve design and production processes; *NATS* and *EUROCONTROL*, where we reduced airline costs through efficient scheduling, and *HSBC*, where we introduced new optimization algorithms to reduce financial risk.

Smaller Companies and SMEs: We also have more specialised links with smaller companies, involving targeted research. Examples include *Lubrizol* (a speciality chemicals company) where we developed statistical design methodologies for screening experiments, *Tetra Pak* where we used mathematical modelling to improve the efficiency of scraped surface heat exchangers used to heat food and *Logical Transport***,** where we designed optimisation software for efficient routing of vehicles, while accounting for a range of complicated constraints.

General Public: The main non-academic beneficiary of our theoretical research in Pure and Applied Mathematics is the general public, and we actively encourage the organisation of large scale outreach events with the aim to raise the profile of Mathematics.

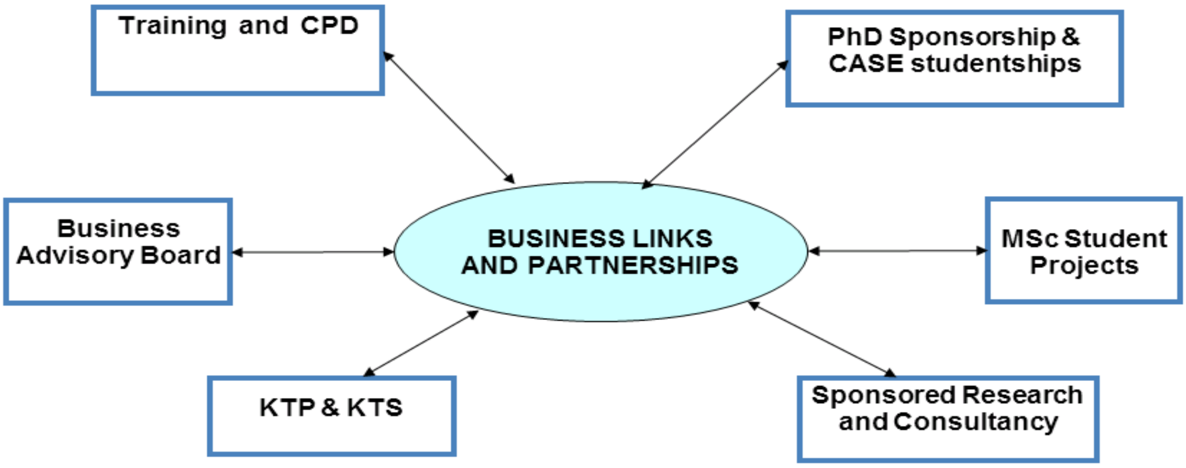
b. Approach to impact

1. Unit support and mechanisms for impact generation.

While we already have exciting and productive links with key industrial partners, we are always keen to develop new opportunities and we have several different routes for doing this, as outlined below. The development of impact is coordinated by our Director of Research in conjunction with our recently appointed Impact Champion and engagement is supported by two Industrial Liaison Officers (ILOs), both experienced scientists, who help staff develop links from informal contacts into financial support for research and consultancy. Each researcher is actively encouraged to engage with end users by their Head of Group with support from the ILOs and mentoring from experienced colleagues. A discussion of opportunities for developing impact form a key part of the annual appraisal and development process, and staff are encouraged to take advantage of the different routes to develop partnerships described below. New links are stimulated by financial support for partially funded industrial PhDs. Mathematical Sciences has a Business Advisory Board chaired by Carole Hooke of British Airways with representatives from organisations such as Shell, Rolls-Royce, J P Morgan, BAA, Dstl and the NHS.

2. Routes to developing partnerships:

Once an opportunity for impact has been identified, we employ the following routes to build links with industry and other users of our research.



A key link with industry and business partners as shown in the diagram is through *MSc projects* with many of the companies involved serving on our *Business Advisory Board*. For example, since 2003, over 30 projects with **Dstl** have been completed, with 10 of these projects leading to *PhD studentships*, consulting contracts and bespoke *training and CPD* with total contract to a value of over £200k. In the REF period Dstl funded a *Research Associate* Fellowship and is a partner in a joint $1 million project between Mathematics, Dstl and the Met Office to apply new statistical methods to understand and incorporate the impact of meteorological variables on dispersion. The interaction with **Ford** and **GSK** followed a similar pattern. Our involvement in over 20 *MSc projects* over the past 10 years led to funding for *PhD students* and then significant *consultancy* projects and *sponsored research*, as described in two of the submitted impact case studies and resulted in a financial commitment of over £300k in the REF period. Through the period, we have used *PhD CASE* studentships to develop research links with the companies listed above as well as **Qinetiq** and **Pilkington.** We run four MSc programmes, which for a large majority of students involve projects in industry or with other end users of mathematics. This high level of interaction with key users has led to a number of new links including significant collaborative research with **Boeing** and **Unilever** which we expect to develop further during the next REF period.

Our involvement with **Logical Transport** (LT)**,** a company that provides integrated transport scheduling software, grew out of a general enquiry followed by an initial consultancy project. This was then supported through a *Knowledge Transfer Partnership* (KTP) project running from 2007 to 2010, where we supplied the Knowledge Base team. Dr Nicholas Pearson was appointed as the *KTP* Associate and LT is now employing him, with the result that in-house OR skills are directly available to the company. Further funding for the collaboration was gained as a *Knowledge Transfer Scheme* (KTS) project in 2010-2011. Another example of a KTP is our work with the **Smith Institute** for Industrial Mathematics and Systems Engineering (the Mathematics KTP), which plays a key role in providing consultancy to bring fresh results and insights that can be rapidly embedded in the wider business environment. For much of the REF period Professor Colin Please was chair of the scientific committee.

Building on our expertise in official statistics, in 1991 we began a collaboration with the **Office for National Statistics** on improving coverage of the UK census. This grew from initial support for *PhD students, PhD internships* and *CPD* activity into two substantial research *consultancy contracts* (worth over £600k in the REF period) on the “Provision of Research Services in Statistical Methodology” which supported the research of 2 members of staff, as described in detail in one of the submitted impact case studies.

We play a significant part in the annual Mathematics **Study Groups with Industry** and held the

EPSRC grant to organise these. Each study group typically involves about 20 academics and 30 PhD students working with representatives from about 6 companies for a week on an industrial problem. These are now held worldwide with our researchers playing a key role. Our involvement in study group research on the planarization of electronic chips led to significant economic impact.

Our Operational Researchers are active members of the **Revenue Management Society**, a group of industry practitioners. We present to them on the relevance of our research and as a result gain insight into real industry issues. Their members sponsor projects, fund consultancy (most recently Global Radio) and recruit our students.

Our **outreach activities** involve high-profile collaborations and participation in impact events. In the REF period we made two contributions to the *Royal Society Summer Exhibition*; “Can you hear black holes collide?” (2008) and “Liquid crystals: living cells and flat screen TVs” (2010) (each event attracting over 10,000 visitors). We contributed to the *Big Bang Fair* (in 2010 and 2013), the largest celebration of science, technology, engineering and mathematics for young people in the UK, attended by over 50,000 visitors. We devised the *National Cipher Challenge* and have been running it for the last decade with support from GCHQ, IBM, and the British Computer Society. The challenge is an annual cryptography competition in which teams attempt to break codes published on our website. Last year we attracted entries from over 2,000 UK school teams.

3. University Support

At University level the Research and Innovation Services (RIS), a specialist department with over 60 staff, provides dedicated support and expertise to facilitate interaction with business partners and support incubation of new businesses. RIS provides access to local and national venture initiatives (such as the SET Squared incubator on the Science Park) that support the development of new business. RIS also manages the University’s long-standing participation in the Knowledge Transfer Partnerships (KTP) programme sponsored by the Technology Strategy Board.

c. Strategy and plans

Our strategic goal is to use the wide range of mathematical and modelling skills within Mathematics to tackle major technological, environmental and societal challenges that our world is grappling with. We will achieve this through the following objectives:

(a) Bringing together interdisciplinary teams in mathematics and other disciplines to approach these challenges in a holistic manner;

(b) Engaging research users at the earliest opportunity in the research process to ensure that the views and insights of our research users inform our research;

(c) Disseminating our research to government, industry, and business users using a wide range of communication channels to maximise utilization of the research findings;

(d) Developing a mechanism for tracking our research and evaluating its impact on the economy, society, and culture;

(e) Integrating our existing mechanisms for the delivery of impact into a single user friendly service.

Mathematical Sciences at Southampton is uniquely placed to tackle research with societal impact by bringing together experts in mathematics and researchers from medicine, engineering, computer science, management and social sciences, into teams offering a diverse set of sophisticated and flexible modelling skills. The University’s Strategic Research Groups (USRGs) facilitate interdisciplinary research and Mathematical Sciences is actively involved in four such groups. Examples of interdisciplinary work to address societal challenges is in Applied Mathematics and Statistics where we explore the role of stochastic processes in biology and work with the Institute for Life Sciences, the Faculty of Medicine and the Clinical Trials Unit at Southampton on the genomics of cancer. Together with the Southampton Optoelectronics Research Centre we applied research from different branches of mathematics to facilitate advanced manufacturing. Support for manufacturing is an area we plan to develop further, and we are bidding (in collaboration with Manchester and Nottingham) to host an industry focussed Centre for Doctoral Training.

In order to engage further with *Industry and Business* we will target stronger links with current and potential stakeholders through special events aimed at specific industrial sectors. Since 2010 we have organised over 20 meetings with end-users of our research to ensure that our cutting-edge research is addressing real world issues and problems of direct relevance to industry, government and other end-users. An example where frontline research in Pure Mathematics has had engagement with key users and embedded impact objectives from the beginning of the project is in work on graphs and power grid blackouts (with National Grid), coarse geometry of large data sets (with support from **IBM** and EPSRC), and work for **GCHQ**. We will continue to further develop this model. Much of our statistical work already has indirect impact on *Government policy.* We aim to enhance this by providing encouragement and funding for impact related activities such as attendance at professional conferences to disseminate research findings and support for developing user-friendly software aimed at non-expert users. We plan to enhance our outreach activities to the *general public* by providing media training and further developing the use of social media for impact purposes.

Our impact strategy will be evaluated by asking all research groups to submit an annual report to the impact champion and using RCUK end-of-award Impact Reports to track our progress.

d. Relationship to case studies

We have submitted six case studies, which exemplify the range and scope of the impact of our research. The demonstrated impact is economic and commercial and also involves health and welfare, environment, and public policy. The submitted examples demonstrate our success in developing collaboration with end-users from seed-funding through to large scale projects. They provide evidence of the efficiency of the processes to develop impact that we have in place and highlight the need to strengthen mechanisms that nurture developing collaborations in the future.

Two of the case studies, ***Making It Count: Improving the Census*** and ***Small Area Estimation: Data Provision for Smarter Local Policymaking***, build on our longstanding relationship with the Office for National Statistics (ONS). The first project deals with improving the accuracy of the UK Census through sophisticated statistical adjustments for missing data and making the fine-grained data available to policy makers through disclosure control. The second case study relates to a new methodology for producing estimates of social and economic indicators for small geographic areas. As a result, Southampton research underpins all the key statistical aspects of the census. This grew out of a specific piece of research on number estimation but has since developed into a significant relationship supporting two members of staff. This is an example where we have targeted a significant stakeholder and developed our research in conjunction with them to significantly increase the impact of our research.

Our work with multi-national companies is represented by two case studies, ***Improved drug development using supersaturated experiments*** (with GSK) and ***Transforming the efficiency of Ford's engine production line***. In both examples an initial project involving a PhD student grew with careful support from the University into a substantial project that improved understanding and produced savings of time, money and effort. This route to impact is mirrored in a wide range of other industrial collaborations including Jaguar, Hosiden Besson, Dstl and Goodrich where we now have very strong industrial links.

The case study ***Using Novel Statistical Modelling Techniques to Deliver More Accurate Air Pollution Forecasts*** is an example where we have deliberately moved into an area with significant societal importance, which poses difficult mathematical challenges and requires the development of new techniques. This research was initially supported by the University at the level of a PhD student and later developed into a significant project involving researchers at the USEPA.

The final case study, ***Optimising Spacecraft Design for A World-leading Space Agency***, provides an example of the wide range of applications of mathematical optimisation. This is an example where one needs to balance conflicting engineering demands to obtain an optimal solution. The project resulted from our direct involvement in a user group forum where we saw how our research could be used by ESA. This led to an initial contract in 2008 which have been followed by a number of regular contracts since then worth a total of over £400k. This has recently led to a £500k clean sky project with Thales.

In all these cases, the presence of an embedded Industrial Liaison Officer, working in conjunction with the central Research and Innovation Services, helped facilitate the relationship between researchers and end users.