**Institution: Plymouth University**

**Unit of Assessment: Mathematical Sciences UoA 10**

## a. Context

The Mathematical Sciences Group at Plymouth University comprises active and committed teams of researchers, who excel in a range of topics. They are united by a common research methodology deriving from large-scale computer simulations that underpins all research across topics ranging from particle physics to medical statistics.

The key strategic decision made in the post-RAE2008 period was to expand expertise in High Performance Computing (HPC), which can be used to solve advanced mathematical problems, as well as applying large-scale computer systems to the analysis of large data sets. The Plymouth Particle Physics Group has attracted world-leading experts with expertise in numerical simulations in quantum physics. In particular, we were able to attract a CERN Fellow, who joined the group in 2012. As part of the UKQCD collaboration, the group has close connections with eight top UK Universities, including Cambridge, Edinburgh, Glasgow, Liverpool, Oxford, Southampton and Swansea. This collaboration involves researchers with expertise that is recognised internationally. It provides a platform for generating impact outside academia, providing opportunities for work with industry and government bodies. Since 2008, the Statistics Group has expanded their HPC simulation remit by gearing research projects to real-life data systems using HPC resources.

The range of applications developed by the group through the newly formed Mathematical Sciences Research Centre includes statistics, industrial and engineering mathematics, particle physics and pure mathematics. Our immediate pathway to making an impact is based upon high performance computing, reflecting our expertise in an area that is the key to enabling a wider range of endeavour at Plymouth University. Beneficiaries within Plymouth include users of tightly coupled computer clusters. Beneficiaries beyond Plymouth include computer hardware developers, such as IBM, FUJITSU and NVIDIA, who benefit from the depth and breadth of the resources, and expertise that we offer. Furthermore, portable computer codes can be used by them for hardware optimisation. Other beneficiaries are SMEs, the general public, and the computer end-user, as our codes are used to quantify the performance of their computer hardware and to identify any design problems with the potential to restrict performance.

In terms of using HPC infrastructure, our applied research benefits government bodies, such as the NHS and the Department of Business, Innovations and Skills (BIS). High-performance computer-aided Bayesian modelling has enabled us to generate extrapolations, using small-area predictions and associated uncertainty estimates, concerning GP practices in this country. This can be applied to the whole of England, and then aggregated as required by policy makers. Our work is substantively more involved and has greater coverage than the small subsets of England that are used in academic publications by others for proof of concept and the development of small area estimation methodology. By increasing the scale of our calculations, our research therefore informs policymaking and influences regulation.

## b. Approach to impact

Since 2008, our approach to impact has been to strengthen our skill set in HPC and large scale computing applications, and to serve our non-academic stakeholders by offering solutions that can be derived from HPC resources. We have identified this as our market niche for impact and have made strategic appointments within our unit. To this end, we have appointed two additional HPC experts with research focus in computational particle physics and three experts in applied Statistics. We are continuously developing novel, computationally intensive methodologies within these fields to address ‘real-life’ problems with a wide range of applications (see below for two indicative examples).

Our pathway to impact is two-pronged: (i) we have established business links in sectors that either have an interest in HPC provision or that rely on HPC resources for their day-to-day business, and (ii) we offer training to spread the word of our expertise and to spark third party interest that might lead to a strategic alliance.

The first pathway is designed to ensure a clear translation of research from active dissemination and engagement to direct benefit. For example, three members of the Lattice Gauge Theory Group, Rago, Patella and Langfeld, sought a strategic alliance with NVIDIA. The group organised a short course on CUDA, NVIDIA's parallel computing platform, in July 2012, delivered by the CUDA expert and particle physicist Dr Ari Hietanen from CP3-Origins, Odense, Denmark. Similarly, members of the Statistics Group, notably Hewson and Stander, drew on their interdisciplinary, international, and government links to explore data provided by the NHS and other beneficiaries, so guaranteeing the relevance, timeliness, and applicability of our work to the beneficiaries. In collaboration with colleagues in Sociology, they used large-scale computer simulations to analyse and cross-reference health-care needs within GP practices in England. The Department of Health has referred to the simulation as the 'Plymouth Model' and has used it to provide indicative allocations of some £8billion of primary health care money for mental health services. This expertise has also proved useful in subsequent work, such as producing small-area estimates of adult skills, as an adjunct to the 2011 Skills for Life survey on behalf of the BIS.

The second main pathway to future impact involves training aimed at dissemination and the building of contacts and influence. We have developed training courses and support material designed to disseminate our work to the widest possible range of end users. An example is the above-mentioned lecture series on CUDA, from which lectures were recorded and made available to a wider audience via various electronic media, such as ITUNES. We are also making available a set of postgraduate courses on the use of Generalised Linear, Additive and Mixed models, initially in collaboration with colleagues in ecology, as well as at Arba Minch University in Ethiopia. By offering such materials through the MSc in CPD route, we have a very flexible offer of state-of-the-art materials that meet clients' needs and draw on our specialist areas.

We have monitored the success of our approach to impact through School and Faculty committees but have now formalised this via the more efficient means of the new Mathematical Sciences Research Centre. We collate feedback gathered during internal evaluations, and from external scrutiny by grant awarding bodies and assessment exercises. We are now actively securing feedback on impact from our external stakeholders and beneficiaries. This feedback informs our strategic planning and decision-making regarding investments in strategically placed PhD studentships or future staff recruitment. For example, we are currently seeking to recruit new members of staff who we expect to contribute to the impact relevant areas Industrial & Engineering Mathematics with a focal point for Advanced Simulations, Statistics and Particle Physics including HPC. Achieved impact is disseminated by the Centre's regular email newsletter to its members and serves as an example of good practice. Impact related research is discussed in our regular seminars and workshops, where staff present their research and its impact. The Centre acts as the point of access for inquiries from industries and third parties. Its steering group consists of representatives from all areas of our research specialism and facilitates contact between external stakeholders and expert researchers.

**c. Strategy and plans**

Our strategy for impact is threefold and based upon:

1. Key appointments of staff with dedicated skills in areas of high potential impact.
2. Interdisciplinary collaborations.
3. Identifying niche markets with a large community of stakeholders.

**1:** As well as increasing the number of staff in our impact related areas of statistics and HPC, we plan to invest through new appointments in a third promising area of Industrial & Engineering Mathematics, in particular the field of computational fluid dynamics. In this field, we can build upon successful past collaborations with, for example, the Plymouth Peninsula Research Institute for Marine Renewable Energy (PRIMaRE) group. In line with the core commitment of Plymouth University, in its Research and Innovation Strategy, to Marine and Maritime issues, our vision for impact here is that these collaborations will contribute to inform safety policies in flood-risk areas, and enable the design of more energy-efficient devices to harness the power of waves.

**2:** Interdisciplinary collaboration has been furthered by the 2013 award of a prestigious EPSRC grant to develop a 'Virtual Wave Structure Interaction (WSI) Simulation Environment' to members of the Advanced Simulations group (Graham and Langfeld), with Prof. Deborah Greaves (PRIMaRE), and scientists from Manchester Metropolitan University and the Rutherford Appleton Laboratory. Our aim is to use HPC computer simulations to develop a *virtual wave tank* that can replace expensive experiments. These simulations might provide a cost effective solution for companies commercializing e.g., on wind or wave energy converters.

**3:** Applied Statistics illustrates our identification of 'niche markets'. A distinctive feature of our approach is to use 'scaling' methods, deriving solutions from small sample sizes and to develop these into real-life solutions for using realistically sized data sets. Cross-disciplinary links provide the knowledge base required for tackling these projects, as well as access to realistic data sets. With respect to scaling, many statistical projects in the field of small area estimation are based on small data sets that can be handled by small computers for a proof of concept. An example is our study: 'Equity in access to total joint replacement of the hip and knee in England', which was based upon data sets from Somerset (*British Medical Journal 2010; 341:c4092*). Our special niche in this kind of data analysis enables us to scale these applications to solve real size problems with data sets from the whole of the country. We can, thus, increase the complexity of the epidemiological model for disease risk and so make the predictions more realistic.

Future plans involve a shift of the target group for 'Cross Disciplinary Collaborations'. The Administrative Data Taskforce (chaired by Sir Alan Langlands) has recently proposed the formation of a UK Administrative Data Research Network, which would be responsible for linking data between government departments. This network could make very large linked data sets available for statistical analysis, with the potential to support government decision-making, by providing consistent and robust information. In view of this development, we have shifted our focus more directly towards collaborations with government institutions such as the NHS and BIS.

**d. Relationship to case studies**

In the selected case studies, we will focus on two showcases, but stress that our group has also made a distinct impact on policymaking via our links with the London Mathematical Society (LMS), which, for example, informs UK education policy in mathematics.

The 'Particle Physics Case Study' is an example of our staffing strategy leading to impact**.** With the appointment of Dr Antonio Rago, the unit has attracted one of the developers of the HIREP code (core for the benchmark suite BSMBench discussed in the case study) and a consultant for IBM. Dr Rago is also well networked in the HPC community and currently facilitating our contacts with hardware companies, such as NIVIDIA.

The 'Statistics Case Study' illustrates our scaling approach, as well as the formation of strategic alliances for impact. Led by Dr Paul Hewson, our Group collaborated with the research group led by Professor Asthana (Sociology and Health Policy, School of Social Science and Social Work), which has a long track record in drafting funding formulae for government bodies, such as the NHS. The research target is to compare the funding strategies 'past utilisation' and 'predicted need'. Our research expertise in the areas of 'disclosure control' and Bayesian modelling has allowed this to be implemented on large-scale computers, in order to produce fine-grained predictions for the whole of England.

Reflection on these highly successful cases through our impact monitoring process (described above) has allowed us to spread best practice to other project work and has informed the refinement of our strategy and approach to impact. The lessons learned through these case studies were central to the decision to form a Mathematical Sciences Research Centre to optimise our engagement and impact.