Institution: Cardiff University

Unit of Assessment: 10

a. Context

Research in the School of Mathematics encompasses a broad range of the mathematical sciences. The beneficiaries and impacts of our research are similarly wide-ranging. Operating at national and international levels, the main beneficiaries of our research include devolved administrations/government agencies in the UK, and commercial/industrial organisations with global reach. Among the key beneficiaries are healthcare professionals and their patients; managers and researchers in industry and commerce who wish to improve the efficiency, reliability and security of predictions and processes; and the general public. The impact of our research concerns not only economic, health and environmental benefits but also societal advancement through public engagement with the mathematical sciences and their applications. Formal activities include impact workshops with end users, the development of educational resources and delivery of school outreach activities, teacher-training events and public lectures.

b. Approach to impact

Our approach to impact derives from our long-standing culture of applied research and direct engagement with a wide range of industrial, government and commercial users through consultancy, knowledge transfer and training, underpinned by fundamental research from across the mathematical sciences. A key component of our strategy to maximise the impact of our research is through close collaboration with users and beneficiaries from the outset. The creation of the posts *Director of Innovation and Engagement* (I&E) and *Knowledge Transfer Officer* (KTO) in 2009 demonstrates the School's commitment to promoting and facilitating routes to impact. The benefits of a dedicated KTO include increased collaboration and grant income from industry.

Engagement with key users. Mechanisms for engagement with key users include:

1. **Long-term strategic partnerships** are a key element of our ongoing approach to impact. During the REF period the School has fostered **strategic partnerships** with more than 10 organisations. For example, the School's **long-term collaboration with the NHS** includes work on improved mathematical and computational models for a range of clinical, epidemiological and health service delivery problems. Transition of the School's healthcare research into effective outcomes has been facilitated through the formation of Health Modelling Centre Cymru (hmc^2), a pan-Wales research centre that collaborates with stakeholders in the health sector (Welsh Government, NHS Wales, Public Health Wales and local Health Boards). The development of impact from our healthcare research will be accelerated through a mathematical modelling unit the School has established with Aneurin Bevan Health Board (ABHB). This major new initiative, based within the Centre for Improvement Focus (Research and Development Directorate) of ABHB, has its research priorities overseen by a joint steering group from ABHB and Cardiff University. Our **strategic collaboration with the Office for National Statistics (ONS)** has led to joint initiatives, workshops, funding PhD studentships and the creation of MSc programmes.
2. **Industry-Academia funding schemes**. PhD studentships have been funded through EPSRC Industrial CASE awards with HP and the ONS; and awards from Cardiff and Vale University Health Board (CVUHB). EPSRC pathways to impact funding has been used (i) to explore the potential of research with the Met Office to provide a hospital demand and resource forecasting decision support tool; (ii) for collaboration across mathematics, computer science and engineering in the aeronautical sector with Airbus and other industrial partners.
3. **Match-funded appointments and studentships.** The School has provided resources that supplement those secured from external funding to support initiatives. These include:

- Match-funding for the LANCS initiative, which allowed the appointment of 4 RAs and 4 permanent lecturers as well as 5 PhD studentships. All LANCS appointees have worked on impact-related research to "bridge theory and practice". Contributions are made across all the LANCS research clusters, and through user-focussed activities, such as workshops, and direct engagement with organisations to tackle global challenges, including those in green logistics, sustainability, and health. Collaboration has occurred with many organisations including Tesco, BA, EADS, Thales, Tata Steel, Lloyds, Admiral, Department of Health, Barloworld, and the NHS.
- Funding for a two-year RA within the recently created Mathematical Modelling Unit in collaboration with ABHB. ABHB have funded an additional 3 RAs (£320k contribution).

- Match-funding for PhD studentships, such as those to strengthen our relationship with HP.

4. **Collaborations.** Many of our partnerships have developed from the impact of earlier collaborative research projects, whilst others are intended to strengthen pathways to impact for current and future research activities such as our work with Thales on new detection algorithms to improve the performance of sonar systems. Our collaborative work with HP (UK & USA) has employed innovative mathematical techniques, which have been incorporated into HP's security software globally (Case Study 2). Another impact case study (Case Study 3) describes the latest impact of a long-term research relationship with Nielsen, the world's largest market research company, in which stochastic modelling techniques have been developed to analyse consumer buying behaviour and to forecast future behaviour.

5. Impact workshops and study groups. The School hosted the European Study Group with Industry in 2011, which brought together over 90 academics and industrialists to tackle a variety of real-life industrial problems. Likewise the School hosted the 2011 international ORAHS (OR Applied to Health Services) meeting, which over 5 days facilitated discussions between 130 academics and health care managers/practitioners, including field trips to hospitals, an opening address by the Welsh Minister for Health, and a keynote speech by the Chair of Public Health Wales. More recently, the School obtained I&E funding to run a series of 'Maximising Impact' workshops to facilitate research engagement between academia and practitioners, including those on 'Systems modelling for emergency care' and 'Subspace-based methods for time series analysis with applications'. Direct benefits from these workshops include a grant award of £195k from the Cardiff and Vale University Health Board following on from the emergency care workshop and a PhD CASE award with ONS whilst planning for the time-series workshop.

6. **Policy advice and international standards.** Staff frequently advise on policy and standards e.g. Griffiths provided advice to the Government in relation to the UK Border Agency problems in the run-up to the Olympics; Pryce is senior technical editor for the IEEE Interval Standard Working Group - P1788. Our research has had a direct impact on the formulation of health policy e.g. helping hospitals (across South Wales, Southampton, London, Exeter, Portsmouth and Reading) accurately forecast emergency demand and schedule hospital resources in response to seasonal fluctuations and meteorological events. Griffiths is mathematical advisor to the Welsh Government.

7. Wider contribution and public engagement. In the last 4 years we have provided outreach events reaching over 1,800 secondary school pupils. We run a series of lectures with high profile speakers (e.g. Johnny Ball, Carol Vorderman), host the UK Mathematics Trust team challenges and teacher-training events, and have developed a range of interactive outreach materials. Staff contribute to national initiatives such as Learn About OR (www.learnaboutor.co.uk) from the OR Society: Knight is Chair of the national OR in Schools taskforce. Harper was co-applicant on the funded EPSRC Partnerships for Public Engagement (with Swansea University, £109k) which, in collaboration with Science Made Simple (www.sciencemadesimple.co.uk), developed and ran public awareness events. We have also secured three year funding to initiate a Cardiff University Mathematics Ambassadors in Schools scheme in which undergraduates will be recruited to create and deliver educational resources in partnership with local secondary schools. Evans initiated the Frontiers Distinguished Lecture Programme of the Learned Society of Wales which has featured Fields Medallists Atiyah, Connes, Vaughan Jones (2011-13).

Identification of resulting impact, an agile approach to opportunities. An agile and supportive approach is taken to maximise opportunities, such as allowing staff to be seconded to industry (and covering teaching duties, for example, to make this possible); recent staff secondments have been to Airbus (6 months) and Welsh Government (2 years), the latter funded by an ESRC and Welsh Government fellowship. Staff are also encouraged to undertake short-term placements to identify future collaborative projects e.g. the HEFCW-funded Strategic Insight Programme (SIP) has been used to support a staff placement at HP Labs (Bristol) working on machine learning, data mining and data analytics. The School benefits from an Industrial Advisory Board (IAB) comprising senior personnel from external organisations including British Airways, ONS, Welsh Government, Admiral, Nationwide and Tata Steel. The IAB assists with identification of impact opportunities as well as contributing to the research-led teaching on our MSc programmes.

Enabling staff to achieve impact from their research and recognition for impact: The impact generating activities of staff are recognised in the School's workload model and are supported by training events and schemes to accelerate the impact of research. For example, EPSRC Impact Acceleration Account funding was used to further pilot the *MetSim* tool for short-term forecasting of

hospital admissions linked to weather in collaboration with the Met Office, moving this tool closer to market. Impact is celebrated through Cardiff University's annual Innovation and Impact Awards (presented by David Willetts in 2012). The School was awarded the Cardiff University Innovation Prize in 2011 in recognition of our collaboration with the ONS.

Other mechanisms to support and enable impact. All students on our MSc programmes (typically 45+ annually) spend 3 months working in industry. Longer-term relationships can arise from these initial short-term projects. This scheme is an excellent way to forge stronger links with industry, and the work of our Masters students and their supervisors often leads to benefit and impact during the projects themselves. Issues relating to impact are routinely discussed and disseminated within individual research groups as well as at School level. The School is represented within the local Innovation Network (www.innovation-network.org.uk) and our KTO is a member of local and national I&E networking fora, thereby ensuring that opportunities are immediately disseminated to relevant staff.

c. Strategy and plans

The School's strategic plan for realising the impact potential of its research identifies the following objectives:

- **Exploitation of interdisciplinary collaborations to reach end-users:** The School will continue to develop embedded strategic partnerships through initiatives such as the mathematical modelling unit with ABHB to enable future impact via rapid transmission of our research ideas to end-users. We will reinforce our collaborative partnership with the ONS by harnessing complementary cross-School expertise in Statistics to create the critical mass to tackle problems of national importance. We will expand the remit of the Industrial Advisory Board for our MSc programme to facilitate our reach to end-users.
- **Staff support and reward:** The School will further enhance the support given to staff for impact activities in a number of ways, including funding for hosting 'Maximising Impact' workshops; factoring engagement and impact criteria into the School's appraisal process, where appropriate; reviewing the weighting for I&E activities in the School's workload model to ensure these tasks are valued; enabling them to take full advantage of existing partnerships (e.g., Cumberland Initiative, LANCS clusters and hmc^2) and actively to seek new openings through networking and training events such as the Research Leadership Development Workshop at Cumberland Lodge, Windsor Great Park (2012) held under the auspices of EPSRC and the LANCS initiative.
- **Raising the profile of School I&E activities:** The School will achieve greater visibility of its I&E activities with end-users through channels including our KTO, the University's Research, Innovation & Enterprise Services (RIES) and the forthcoming College Business Gateway, planned for 2014. We will develop our School I&E webpages to include a searchable database to capture all collaborations with end-users and to promote and celebrate the impact of our research achievements using multi-media resources. We will expand the portfolio of Masters-level training programmes with industrial placements and use the network of companies to foster future impact-related activities such as match-funded studentships and consultancy. We will continue to seek advice on all aspects of I&E from organisations such as the IAB, the Council for Industry and Higher Education, the UK Innovation Research Centre, and research funders.

The School's future plans are based on the conviction that many of our core research themes in OR, data mining, and computational and statistical modelling impact on health, security and wealth generation and we will continue to enhance them in our future research activities.

d. Relationship to case studies

The case studies reflect the strongest examples of the School's impact with respect to reach and significance.

Case study 1 exemplifies a longstanding tradition of research in the School to enhance the efficiency and effectiveness of a wide range of healthcare services achieved through a long-term collaborative relationship with the NHS.

Case study 2 illustrates the way in which CASE and match-funded studentships have been used to promote engagement and collaboration with HP in the development of commercial document security techniques.

Case study 3 highlights the way in which a long-term research relationship developed through a series of research contracts has been used to embed cutting edge statistical modelling techniques in the consumer behaviour forecasting operations of Nielsen.