Institution: UDur: University of Durham

Unit of Assessment: Unit 10: Mathematical Sciences

a. Context

The unit's research has had an impact on the following non-academic user groups, beneficiaries and audiences:

Economic Impact: The unit has engaged with a wide variety of companies, from large-scale multinational corporations to SMEs. This typically comes via industrial collaborations and consultancies with part or whole company funding, combined with research council support.

Public sector (general): Impacts on the public sector exist in the areas of healthcare delivery, management in the Home Office, and national security.

Public sector (policy): There have been significant policy contributions into a number of areas, including climate change, ecotoxicology, dietary exposure to pesticides, energy-related risk, and manufacturing reliability. Beneficiaries are at national, EU and international levels and include the Met office, FERA, the FSA, the HSE, ESA, EFSA and the OECD.

Societal Outreach: The targets for outreach activities by the unit include the local community and schools, national and international audiences for radio and television programmes, and engagement with the teaching of mathematics in Africa.

The majority of the impact from the unit on non-academic users comes from work of its statistics group, followed by parts of the applied group. For the pure mathematics and mathematical physics sections, non-academic impacts have principally been on national security via secondments to the Heilbronn Institute and through outreach activities.

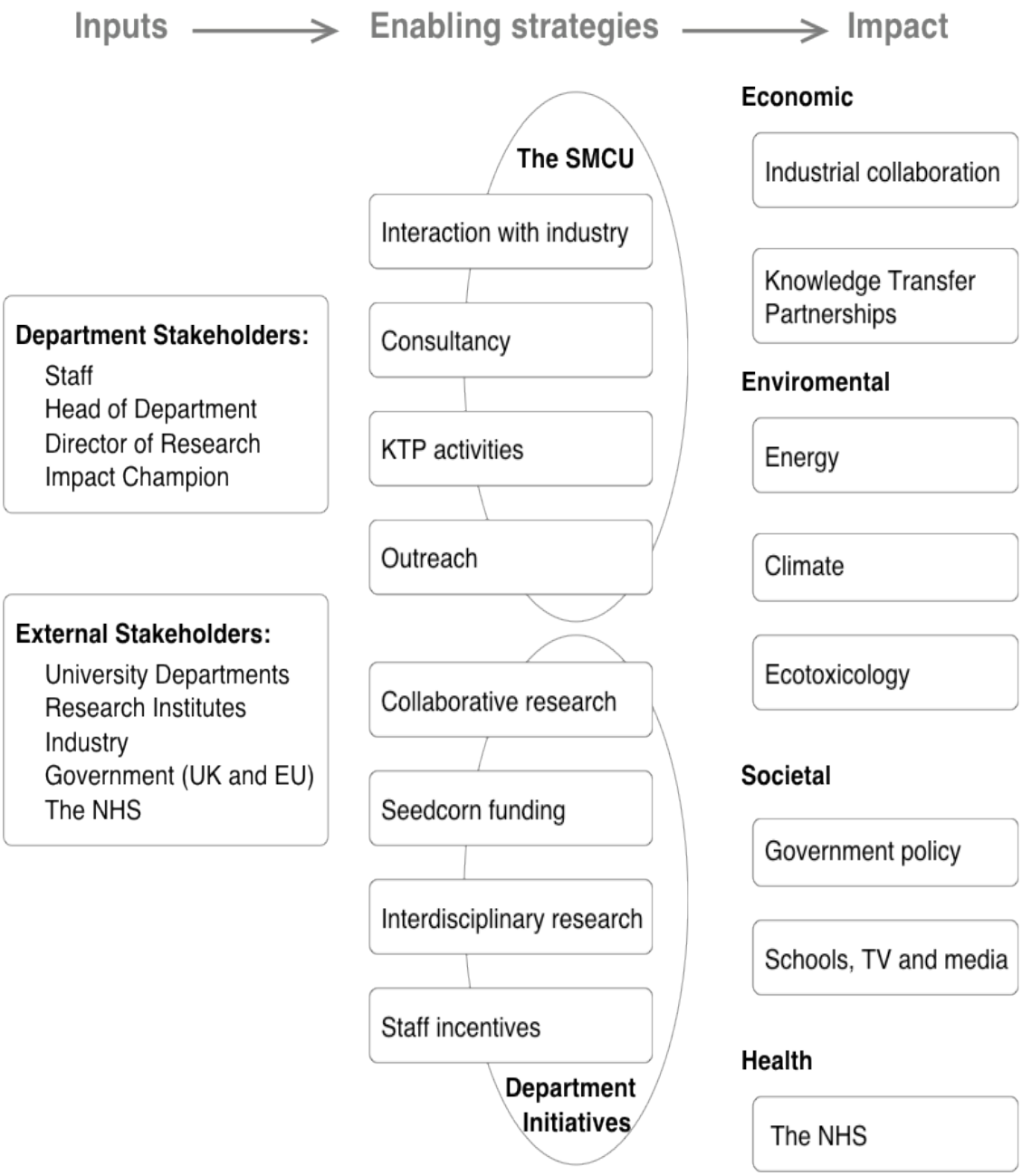
b. Approach to impact

Much of the unit's impact is channeled through the Statistics and Mathematics Consultancy Unit (SMCU), which was established in October 1996 with the specific aim of attracting commercial research and consultancy work to the Department and its members of staff, and with providing the Department with a focus for external liaison for outside and commercial organisations. In the first 16 years of its existence the SMCU has grown from nothing to annual turnovers of over £100,000. These activities are core to the University's stated mission, with respect to supporting the regional economy, commercialising research and enhancing the University's research infrastructure. Commercial clients of the SMCU include the Home Office, British Telecommunications Plc (now BTexact Technologies), Thorn Lighting Ltd., Syngenta, Unilever, Philips Components Ltd., UK Government, Czarnikow Sugar Ltd., University Hospital of North Durham, Energy Scitech Ltd. and subsequently Roxar Ltd., the Environment Agency, Ikeda-Hoover Ltd., Johnson Controls Ltd., NEDL, Northumbrian Water, Imperial College London, SilentNight Furniture Ltd, Summit Media Ltd, Viskase Ltd., the UK charity SCOPE, and numerous smaller companies. Much of the work requires novel statistical methodology and relies on theoretical work developed in the Department. The SMCU has had Knowledge Transfer Partnerships (KTPs) with the Northern Doctors Care Group, Energy Scitech Ltd, Suregrave Ltd, and Summit Media Ltd (two programmes).

The unit has worked closely with Durham University Research Institutes, especially the Institute for Hazard, Risk and Resilience (IHRR) with which members of the statistics and applied groups hold a 'Tipping Points' grant from the Leverhulme Trust. This has led to significant impacts in the health sector through the development of models for health related issues such as alcoholism (binge-drinking), smoking, obesity, and the spread of virus through a community. This is conducted with the NHS via the North East Public Health Observatory which is based in the Wolfson Research Institute in Durham University's Queen's campus at Stockton. The work also involves members of the Anthropology Department in Durham University, Paul Ormerod of Volterra, and the Institute of Advanced Study, Durham University.

A further example of interdisciplinary work fostered by a research institute leading to impact is

the on-going project of Dr Ian Vernon and Professor Michael Goldstein with members of the Institute for Computational Cosmology on the GALFORM model, using Bayesian emulation methods in the history matching of galaxy formation simulations. This model has been used by the European Space Agency (ESA) to generate mock catalogues for the calibration of satellite equipment.



The University and Research Institutes provide seedcorn funding for projects, and useful contacts to help in their development. An example involving the Durham Energy Institute is a project, effectively initiated in April 2011, to improve policies for managing wind power and solar power via better methodologies for dealing with severe uncertainty in the renewable energy community. The work is in collaboration with the Idaho National Laboratory (INL) through Mr Jake Gentle, an electrical engineer who manages wind and solar farms. The University's Engineering Department is also involved, in particular Professor Phil Taylor (an expert in renewable energy and electrical networks, now at Newcastle) and Dr Grant Ingram (an expert in computational fluid dynamics). The current target is to enable short-term prediction of wind speeds along transmission lines to improve the statistical modelling of real-time line ratings, using various data assimilation algorithms and state-of-the-art decision methodology (the

Durham Statistics Group has world leading expertise in both these areas) in conjunction with computational fluid dynamics solvers (Dr Ingram). These predictions will enable utility companies to put more power through existing network infrastructure, which will be crucial as more wind farms are connected to the grid. The Durham Energy Institute awarded Dr Troffaes a £3k scoping grant in April 2011 to initiate this research, which was followed by a £7k programme of work grant, awarded to Dr Troffaes and Professor Taylor, again by the Durham Energy Institute, in December 2011. Mr Gentle at the INL was also awarded a $21k Faculty Staff Exchange grant to support this research. In 2012, Troffaes and Ingram won a £10k Impact Award from a grant to Durham University under EPSRC's Institutional Sponsorship scheme, which funded a workshop on uncertainty quantification and risk informed decision making, aimed at facilitating the link between industry and academia. An additional £2k DEI grant was obtained to enhance the interdisciplinary nature of the resulting research.

Another example, showing how seedcorn funding has helped develop impact for junior members of staff via smaller grants, was the Durham Energy Institute grant of £3500 to Dr Abigail Wacher (a lecturer in the computational applied group from 2009 to 2011) for "Efficiently solving systems of ordinary differential equations arising in wave energy modelling". This contributed to the establishment of industrial contacts in the area of wave energy, including with Tecnalia and its subsidiary OCEANTEC in Spain.

Exchange programmes with industry and government agencies have proved very fruitful in the generation of impact. For example, relationships with FERA initially established by Professor Coolen, later joined by Dr Craig, led to an ongoing programme of joint PhD supervision, and to contacts between Dr Craig and the FSA, EFSA and OECD with impacts on environmental policy, some of which are contained in one of the unit's case studies.

The unit is also engaged in international collaborations leading to impact. In one on-going example, Dr Patrick Dondl is working with experimental researchers on an interdisciplinary project whose goal it is to understand the formation of self-organised microstructures in plastically deformed metals such as TWIP steels. This research is in collaboration with the Max-Planck-Institute for Iron Research (partly funded by the steel industry through the Stahlinstitut VDEh), and aims to provide insight into orientation patterning relevant to the computational modeling of these materials.

Members of the unit have been active in the general dissemination of research to public audiences, through talks and media such as radio programmes, television documentaries and films. The unit has significant relationships with schools in North-East England, and has been active in establishing links for the teaching of mathematics in Africa, through the African Institute for Mathematical Sciences (AIMS); these links led to the signing of an MoU between Durham University and AIMS Ghana in 2012. The unit contributed around 106 days of effort through outreach exercises in 2012-2013 (source: HEBCIS data collection exercise).

c. Strategy and plans

The examples given in section **b** above illustrate how the unit is able to interact with wider university structures in order to increase the impact of its core research activities. Many of these structures stem from university-wide decisions to embed the generation of impact and the creation of pathways to impact at the core of its current strategy. In particular, under Aim 1 of the University Research Strategy 2010-2020 is

Objective (iii): To deliver research in every discipline that addresses questions and issues with the potential to make significant impact on knowledge, people, the economy, or to enhance or change society for the better.

and, under Aim 3,

Objective (iii): To develop creative research partnerships with influential national and international businesses, research councils, spin-out companies, non-governmental organisations and public sector bodies with mutually beneficial research agendas.

Impact is being embedded at all levels of academic development: recruitment, appointment, probation, staff development, research leave and promotion now incorporate and incentivise impact, and annual Awards in Excellence in Research Impact have been instigated, to start in

2014. Within the unit, the post of Impact Champion has been created, to oversee and encourage all aspects of research impact. As a concrete recent example of the effect of these policies, in the 2011-12 promotions round, impact was a key feature in the promotion cases for two academics from the unit, namely Drs Peter Craig (promoted to Senior Lecturer) and David Wooff (promoted to Professor).

A part of the unit's five-year plan is the objective to increase collaboration with industrial partners, government agencies and other external stakeholders. This reflects the intention to build on current links, especially with companies such as Roxar in the oil industry, to support research positions within the unit and to instigate industrial support of research visits by academics to industrial facilities making use both of Departmental funds and the University's seedcorn fund. The unit is already encouraging links with particular industrial partners, such as IBM, BG Group plc and Summit Media, and the five-year plan includes a commitment, now approved by the University, to a further academic appointment to the SMCU, dedicated to liaising with industry. The plan also calls for the creation of opportunities for students as well as staff to link to industrial employers, by developing a new undergraduate programme with a year in industry, and by seeking research problems from industry for use in undergraduate final year projects. Durham is scheduled to host a study group as part of the Knowledge Transfer Network in Industrial Mathematics in 2017. This annual event involves around a hundred academics and industrialists getting together in week-long workshops to study a selection of deep problems whose solutions would result in significant industrial innovations. This will build on the already very fruitful interactions between the unit and the Knowledge Transfer Partnership (KTP) scheme: the Department has to date been granted six longer (at least two-year) KTP awards, more than any other mathematics department in the country.

The unit aims to seize opportunities to enhance impact as they arise. To give one example of its agile approach, together with BG it is developing a bid to the Brazilian government as part of their Science without Borders scheme. This will develop the unit's fundamental work on Bayesian methods and apply it to the analysis of oil-well depletion. A pilot sum of $6M has been awarded to fund Brazilian students to spend two years out of their four-year PhD programmes in Durham, working on the application of Bayesian methods in the oil industry. After the initial year the scheme will be broadened to involve the Departments of Earth Science and Engineering, at an ongoing level of $6M per year. With students spending half of their time with mathematicians and half with petrochemical engineers, this programme will develop significant economic impact in the coming years.

Active steps are being taken to broaden the impact of the unit's activities to other research groups, as exemplified by an ongoing investigation of the properties of solid foams by Drs Chakrabarti and Piette of the applied group, where contacts with the two principal industry stakeholders in the work, namely FnE Saddles and Carpenter co, have been facilitated by the injection of Departmental resources to fund site visits.

d. Relationship to case studies

Since 1996 the unit's approach to generating commercial research income has principally flowed from the activities of the Statistics & Mathematics Consultancy Unit (SMCU), in tandem with the exploitation of the applied research interests of individual colleagues – especially in statistics and numerical analysis. More recently the Department has fostered a greater involvement in attracting commercial research and the underpinning of commercial research carried out by colleagues in different disciplines. However, many of our case studies predated these developments, and emerged organically because the right "growing conditions" existed. The Statistical Modelling for Digital Marketing case study arose through Durham's high reputation and the existence of the SMCU and its record of successful partnerships. Another (ENABLE) arose from long and mutually profitable relationships with a company selling know-how to the oil industry, and which has involved research carried out by several members of the statistics group going back many years. Mathematical Science is an underpinning discipline, and the research we carry out tends to be reflected in work without which progress in other disciplines would not be possible.