Institution: University of York

Unit of Assessment: 10, Mathematical Sciences

a. Context

Overview. Mathematics at the University of York (UoY) is committed to, and has a long history of, enabling impact across its full range of work, from pure mathematics to computational techniques, across the Department of Mathematics and the interdisciplinary York Centre for Complex Systems Analysis (YCCSA). Impact arises principally through close cooperation with industrial, government and European partners in the creation and application of new techniques, and through knowledge transfer, including professional development and training, and the stimulation and influencing of policy debate. The department has a continuing programme of public engagement, with events at local, regional and national level, with its research featured many times in publications such as *New Scientist*. Forms of impact include*:*

Direct engagement with industry and government agencies – e.g. in metabolomics and genomics (Wilson, with the *Food and Environment Research Agency* (Fera) **[Food safety and traceability case study, C1]**, *Astra Zeneca, GlaxoSmithKline* and *Molecular Dimensions*); in quantum information (Colbeck via *ID Quantique*); in number theory, where research is finding applications in communications/signal processing (Beresnevich, Levesley and Velani via *BT* and *Bell Labs*); in mathematical finance (Zastawniak via *RiskMetrics*).

Influencing policy debate – e.g. in mathematical biology, informing the policy debate on fisheries (Delius, **[Balance harvest, C2]**, and Pitchford); in statistics, enabling better standardisation of health state measurements (Kharroubi); in networks and nonlinear dynamics, where Smith's research **[Traffic flow, C3]** has led to better models for traffic flow and traveller choice.

Training of professionals – e.g. MacKay's mathematical modelling of combat, which has led to better understanding of attrition scaling **[Mathematical models of war, C4]**; and in mathematical finance, through the part-time and online MSc programmes and associated activities.

Outreach and public engagement – across research fields, building from local school and public activities to major national events (see *e.g.* Twarock's range of activity in Sect. **b** below).

b. Approach to impact

The department has a threefold strategy, of: (1) creating the potential for impact, by facilitating connections and exchange of ideas; (2) developing research and enabling impact, by shaping the progression from research to application; (3) supporting and building impact, strengthening existing links and continuing their impact. Across all these stages the department aims to build strong relationships with its users and potential users, and is supported by an Advisory Board, whose current members include alumni, the directors of Fera and the *Smith Institute*, the previous director (2009-12) of the *Heilbronn Institute,* and senior staff from *Barclays Capital* (*BarCap*), *BAE Systems*, *BT*, and the *Institute and Faculty of Actuaries* (IFA). In the other direction, for example, Pitchford sits on the Scientific Advisory Committee of the *Centre for Environment, Fisheries & Aquaculture Science* (CEFAS). CASE studentships have been supervised with partners CEFAS, Fera, *AstraZeneca*, *BP*, the *British Antarctic Survey* and *Microsoft Research*.

Under (1) the unit aims initially to discover connections between different areas of mathematics and with disciplines outside it, and seeks applications via industrial and other external users. To do this, the Department encourages (and where possible funds) colloquia, away days, and the hosting of workshops. For example, Wilson's, with Fera in 2008, led to significant impact, and her work currently underpins £8M worth of current Fera projects. Interesting connections can be developed this way: for example, communication, antenna design and signal processing is an active area of application of the work on rational approximation of Beresnevich, Levesley and Velani, and is currently being explored with Electronics at York and with *BT Innovate & Design* through a joint 2013 workshop. Focused bi-lateral visits with electronics experts worldwide form a core activity of the Number Theory group's current £1.6M EPSRC programme grant. Internally, the Department funds travel and collaborative pilot projects on the same basis as established research, and encourages collaborations across and outside mathematics (*e.g.* archive visits to support

MacKay's work on historical operations research). Applicants for all forms of funding, including research leave, must consider their work's potential for impact. The UoY also provides research priming funding, used *e.g*. to explore work with Health Sciences on social inequality. The Department maintains contact with alumni, partly through annual speaker days, and explores mutually beneficial collaborative possibilities, which are developed in consultation with the Advisory Board. Interdisciplinary research connections are promoted through YCCSA, which houses staff from Mathematics, Biology, Chemistry and Computer Science in the £20M, award-winning Ron Cooke Hub. YCCSA's activities bring together many other staff and have resulted in various exciting recent collaborations, resulting in 2012 *Nature* and *Science* papers on ecology and complexity, both of them the kind of pure science which we aim to steer towards impact. Achievement in enterprise, innovation, public engagement and knowledge transfer is explicitly recognised by the university's promotions criteria at all levels.

Examples of work building towards impact (2) include: Kharroubi's international comparisons of health state measures, aiming to influence policy through NICE; Pitchford's modelling of marine reserves; and Busch and Colbeck's work on quantum information protocols. Further developed are Twarock's ground-breaking work on viral structure, now filing for patent (GB1315785.4, 9/2013) and with the potential to enable new anti-viral therapies; Pitchford's work to reduce toxicological animal testing (supported by NC3Rs, presented at an *AltEx* industrial-academic workshop, and now pursuing a PhD studentship with *AstraZeneca*); and A. Wood's joint BBSRC IIP award with *Citration Technology* to look at creating citric acid from biofuel waste. None is yet among our case studies. To nurture such work through to impact, the department has an Impact Development Manager (an academic role), who liaises with the UoY Research Innovation Office, promotes consultancy and funding opportunities, and advises colleagues on building external collaborations.

Under (3) a recent initiative has been to formalise the Department's consultancy. Building on strong examples such as Wilson's work for *AstraZeneca* [analysis of crystallisation images] and *Molecular Dimensions* [licence agreement for imaging software], we promote opportunities to staff and pro-actively seek new possibilities based on colleagues' research, connections and knowledge, utilising UoY Knowledge Transfer and networking activities. A recent (2013) example concerned quality control at leading bio-tech firm *Eluceda*, which, following initial success, is now being developed into a project proposal for *Proctor and Gamble.*

An emerging theme under (2, 3) is the energy market, in association with 2013 appointees Knight and Kang (see Sect. **c**). Kang's interest in the market in energy futures and other derivatives, partly with *Lacima Group*, connects with the existing work of the Mathematical Finance group. Knight has used wavelet decorrelation properties to develop new techniques for nonstationary time series. Working with *EDF* and *Shell UK,* and supported by funding under EPSRC's call for research on energy challenges, she has significantly improved wind farm efficiency. This in turn links with the work of Pitchford and A. Wood on flocking and wind farm bird-strikes, and with Bees' work on biofuels. Various activities are planned to develop this nexus, including a joint academic-industrial research meeting for 2014.

The Department adopts a similar approach to public engagement, with a programme of school visits, public lectures, and STEM ambassadorships, building through regional level (*e.g*. MacKay and A. Wood for the *York Festival of Ideas* and Sudbery's quantum information lectures) towards events of greater reach and significance. One example is Twarock's mathematical virology research, which was presented in an *Isaac Newton Institute* case study, an EPSRC parliamentary event, the LMS 2008 Popular Lectures, the British Science Association and other science festivals, and features in many articles and books, such as Ian Stewart's *Mathematics of Life.*

The Department encourages colleagues to inform and influence the policy debate both indirectly and directly through service on outside bodies (*e.g*. MacKay on ACME, Pitchford for CEFAS). All buy-out is used to reduce teaching and administration rather than research time, while consultancy and other fees are allocated to a personal account. A workload model gives full weight to impact activities such as public engagement. Examples of study leave used to further impact include Delius's 2009 & 2013 visits to Berlin, Zurich, Bielefeld and *Microsoft Research* in Cambridge.

c. Strategy and plans

Our Impact Strategy is formulated by Departmental Research Committee (DRC), agreed by the University and coordinated by the Impact Development Manager (IDM), an academic role within DRC. It is built around the three stages described above, and aims to embed short-term, agile responses to new possibilities for impact (as in Sect. **b**) within a longer-term integrated approach, which links appointments, research, and the building of external engagement through advice and consultancy, PhDs, MSc supervision and placements, and joint workshops for knowledge transfer. These activities are supported by UoY/EPSRC External Engagement funding of £20k (11/2013).

Capacity for impact is created by strategic appointments, For example, the 2012-13 appointments of Bees in mathematical biology, Knight in statistics and Kang in mathematical finance create a centre with significant range and impact potential for energy delivery and security. More such appointments are planned. The department also strongly supports colleagues in pursuing significant new research directions. Both Wilson **[C1]** and Delius **[C2]** began their careers as pure scientists, followed their interests in new directions, and are now having significant impact.

MSc/MRes programmes are developed to support groups with impact potential, *e.g*. Statistics, and Mathematical Finance, Biology and Chemistry. They enhance connections with industrial partners via their hosting of masters and PhD students. Building on previous EPSRC and NERC-funded MSc/MRes courses, new examples include a Statistics MMath/MSc (2012), to support both mathematical and applicable statistics, including health and ecological statistics; and an MSc in Advanced Mathematical Biology to support ecosystem, epidemiological and microbial research (to begin 2014). These complement our highly successful portfolio of online, full- and part-time MScs in Mathematical Finance, in which students have worked as interns at, and on dissertation topics proposed by, *e.g. RiskMetrics*. This is being developed further, in consultation with Advisory Board members and others, with the aim of extending links with the financial sector.

Consultancy is developed by the IDM, who also actively facilitates joint academic-industrial *Workshops* (both as described in Sect. **b**). For example, the recent Number Theory – *BT* workshop has acted as a catalyst for a potential EPSRC fellowship application under the Priority Area *New Connections between Mathematical Sciences and Information Communication Technologies.*

d. Relationship to case studies

[C1] Mathematical methods to improve food safety and traceability. Former number theorist Wilson now works on a broad range of mathematical techniques for the modern chemical and bio-tech industries. The development of her work exemplifies the value of MSc courses, joint appointments and the YCCSA multidisciplinary context in sustaining long-term relationships with research users such as Fera, and enabling exchanges of people, techniques and knowledge at all levels from MSc through PhDs and RAs to academic staff.

[C2] Balanced Harvest: Mathematical underpinnings of a sustainable fisheries policy shows the importance of fundamental research in mathematical ecology, and the value of pursuing new research directions. New ecological models, emerging as continuum limits of stochastic models of marine organism interactions, allow us to understand the dangers of selective fishing in destabilising ecosystem dynamics, and are beginning to effect a fundamental shift in fisheries policy towards balanced harvesting. This illustrates the importance of supporting a colleague (here former mathematical physicist Delius**,** with leave in 2009 and 2013) in moving into a new field.

[C3] Mathematical Modelling to Improve Traffic Flow and Control exemplifies much of the department's approach to impact, especially via MScs and local external collaborations; overlapping research interests in nonlinear dynamics and number theory have led to a range of past (including pre-2008 patents) and possible future impacts.

[C4] How far can mathematical models of war and combat be trusted? exemplifies the impact of interdisciplinary research facilitated by creative use of small amounts of pilot funding, here in work by MacKay (including extensive archive visits) with historian C. Price to place mathematical operations research in a richer historical context, in which its interplay with historical actors and organisations can be explored, thereby extending its relevance to current military practice.