

**Institution:** The University of Leeds

**Unit of Assessment:** B10, Mathematical Sciences

**a. Context**

*(Glossary of research groups mentioned frequently in REF3a. Additional groups are spelt out fully.)*

<b>PIM</b>	Polymers and Industrial Mathematics
<b>AGFD</b>	Astrophysical and Geophysical Fluid Dynamics
<b>MBM</b>	Mathematical Biology and Medicine
<b>PSMFM</b>	Probability, Stochastic Modelling, and Financial Mathematics
<b>STATS</b>	Statistics

**(i) Non-academic beneficiaries.** As a result of the unit's wide-ranging and interdisciplinary research, the main non-academic user groups and beneficiaries span diverse areas of application. The examples below demonstrate the broad extent of the unit's research impact, which ranges from the guiding of policy (based upon theory) to design, manufacture and implementation (based upon advanced numerical methods and delivery of computational software).

- **Industry** (*cost-effective enhancement of technology*). The unit's application-driven research collaborations are developed to yield beneficial outcomes (see Case Studies, hereafter "CSs") for commercial companies in technological and industrial sectors such as: plastics and polymers (molecular dynamics and structure - BASF, Dow, DSM, ICI, Ineos, Lucite, LyondellBasell, Mitsubishi Chemicals, ExxonMobil); printing (inkjetting/printers - Xaar, Domino, Linx, Inca Digital, GlaxoSmithKline, SunChemical, Fujifilm Sericol); energy sector (gas release from pipelines - British Gas); fire-safety (steel protection via intumescent coatings - PPG Performance Coatings).
- **Government** (*cost-effective improvement of national security*). The unit's research has assisted British security services via collaborations with MoD Fort Halstead (body and vehicular armour for UK Forces) and airport security (image recognition and forensics), and with Dstl Porton Down (pathogenesis and host-response within the human body).
- **Health, Health & Safety** (*influencing the environment, health practice & policy and Health & Safety*). The unit's research includes: informing the National Grid's assessment of the hazards in its planned pipeline transportation of dense-phase CO<sub>2</sub> for carbon sequestration; informing pharmaceutical companies on replacing animal testing with mathematical modelling (Unilever).
- **Finance** (*improving the economy*) In collaborations with international consultants Aon Hewitt (late-retirement effects on pension-fund sponsor-trustee relationships) and the National Australia Bank Group, the unit has developed financial models for retail banks to improve *customer offering*.
- **Policy and Public Engagement** (*advising legal process, advising scientific policy, managing scientific events*). The unit's research has: informed expert legal testimony in death-penalty cases (L.A. County Court, USA); influenced a NASA advisory panel (on solar magnetic activity); led to public engagement through mathematics publications intended for a wide public audience, and coordinated and promoted public events (especially the international Turing Centenary in 2012).

**(ii) Impact relationship with unit's research groups.** The unit's interdisciplinary research expertise accounts for the diversity of impact listed in **§a(i)**, and it is within the following research groups that impact generation, and the potential for it, has been most promoted and fostered.

- **PIM** - Impact has arisen (CS2, CS5, CS6) via development of commercial and open-source software for analysing real-world problems, motivated by diverse commercial and governmental requirements. In addition to the list of companies listed in **§a(i)** under **Industry** and **Government**, **PIM** has (or has had) collaborations with, e.g., Japan Polychem and AkzoNobel.
- **AGFD** - Impact has arisen (CS3) from theoretical and numerical expertise applied to predicting solar activity. The transferability of the group's expertise has allowed it to inform commercial assessment of transportation hazards for fuel and CO<sub>2</sub>. **AGFD** has external links with British Gas, the National Grid, the Met Office, NASA, NOAA, Tata Steel, MTI Holland and MRI Netherlands.
- **PSMFM** - Impact has arisen (CS4) through the development, implementation and integration of a *customer-lifetime-value* statistical tool into the infrastructure of Yorkshire Bank.
- **STATS** - Impact has arisen (CS1) through the use of expert legal testimony in death-penalty cases to identify brain damage caused by fetal-alcohol syndrome. Impact potential (for two nascent CSs) is developing via assessment of protein structures for drug synthesis, and research in *elicitation of expert knowledge* for toxicological risk assessment (Unilever) for predicting costs of infectious diseases and advising on alternative approaches to testing products on animals.

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- **MBM** - Impact potential is developing through: recently (2011/12) funded projects in skin sensitisation (Unilever) and vascular endothelial growth receptor dynamics (AstraZeneca); modelling bacterial pathogenesis (Dstl); quantifying genetic factors associated with the risk of heart attack (NHS) using methods developed in Statistical Bioinformatics.

**b. Approach to impact**

- **Development of relationships with key users and nature of relationships & interactions.**

**Strategy and reputation.** The unit's external links have been catalyzed through a combination of proactive strategy (see §c) and research reputation; the value placed by companies on quality research has been a significant factor in drawing end-users to the unit. As a result, during 1/8/08-31/7/13 the unit has been awarded 10 grants of cumulative value ~£950k from industrial, governmental, and international sources in the diverse areas listed in §a(i), together with £126k consultancy (see below). The unit has adopted a flexible approach towards research engagement with non-academic beneficiaries, as shown by its creative shift in emphasis from traditional heavy industry towards finance, environment, mathematical pharmacology and complexity science for social media (see §c and antepenultimate paragraph of §b).

**Links to key users.** The unit encourages staff to identify research areas (e.g. polymers, thin-film fluids, immunology and finance) with potential for impact. Initial connection with companies may be established through: reputation (see above); staff initiatives; external research collaborations; industrial-placement companies (see below); KTN workshops and sandpits (see below). After meeting to explore common ground, collaborative research then generates the potential to develop impact. Through this approach, the areas of the unit's impact (and contacts for public engagement) have expanded during 2008-13 to augment engineering-related industries with (see §a and §c) finance, health, the environment, complexity science.

- **Interactions with key users.**

**CASE studentships.** The unit's strategy has increased the take-up of awards funded jointly by research councils and industrial partners. During 2008-11, 3 CASE PhDs were completed whereas, during 2011-13, 6 CASE PhDs commenced; with Procter and Gamble<sup>†</sup> (†=new link in REF period), AWE, AstraZeneca<sup>†</sup>, Shell<sup>†</sup>, GlaxoSmithKline and the Met Office<sup>†</sup>. By expanding this aspect of PhD provision, further links have been developed with BP<sup>†</sup>, Central Science<sup>†</sup> Laboratory<sup>†</sup>, and Nestlé<sup>†</sup>. The unit now has a commitment to create at least 1 CASE award p.a.

**Research contacts via Industrial Placements.** The unit has developed links with commercial (predominantly financial) companies via its burgeoning *Year-in-Industry* undergraduate programme (81 students in 2008-13). One placement resulted in software for optimizing airport-traffic logistics that has been adopted for operational use by NATS. MSc dissertation projects are jointly supervised by the NHS Information Centre.

**Knowledge Transfer.** The unit has an ongoing programme of KT Workshops and Sandpits that are well attended by industrialists, among whom the unit's profile is accordingly increasing. CS4 is based on a Knowledge Transfer Partnership (KTP) formed between Yorkshire Bank (National Australia Bank Group), Leeds Univ. Business School and Schenk-Hoppé (**PSMFM**); the KTP received an ESRC award for "*Best Application of Social Science in a KTP in 2011*".

**Training Networks.** The unit has run three graduate-level EU-funded Marie Curie Initial Training Networks (ITNs) with links to industry. *DYNACOP*, in complex macromolecular fluids, was coordinated by the **PIM** group jointly with Physics (industrial partners BASF and Dow). *QuanTI*, in quantitative T-cell immunology, is coordinated by the **MBM** group (industrial partners Bayer, AstraZeneca, Unilever and Microsoft Research Cambridge). *MALOA*, for PG training in Mathematical Logic, is coordinated by the **Logic** group (industrial partners BT and Onera).

**Intermediaries.** Kent and Mardia (**STATS**) have informed the research of Bookstein (Vienna and Washington), the intermediary in CS1. Partington (**Analysis**) has had long-term collaborations with the French Institut National de Recherche en Informatique et Automatique (INRIA): software based upon his work in operator theory has been implemented by intermediary INRIA for use by Le Centre Spatial de Toulouse and Thales Alenia Space in the field of space telecoms.

**Consultancy.** External requests for consultancy arise predominantly through the reputation of the unit; they are coordinated at faculty level by a service that provides administrative support for external links (see end of §b). During the REF period, 8 members of the unit obtained a total of £126k via 21 consultancies for partners in commerce, industry and healthcare. In the largest of

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these (£45k), Kelmanson (**PIM**) worked for an internationally leading protective-coating manufacturer on the mathematical modelling of intumescent paints as a fireproofing agent for steel structures; his resulting study will inform and amend existing relevant European (safety) standards. Members of the unit have also acted as expert witnesses for the CPS.

**Public Engagement.** Opportunities for impact through public engagement arise through overall research reputation or by supporting individuals committed to wide scientific dissemination. Three examples are as follows. Cooper (**Logic**), as a result of his research in computability theory, was Chair of the “*Turing Centenary Advisory Committee*”, which in 2012 coordinated an array of international academic and public events celebrating the life and influence of Alan Turing. During the REF period, Elwes (**Logic**) has published five commissioned popular-mathematics books, and has also written articles in *New Scientist*, *The Daily Telegraph* and elsewhere on a number of mathematical research topics. Evans (**PIM**) has written six feature articles for the BBC’s *Sky At Night Magazine*, and is one of nine official bloggers for the *Physics Focus* website of the Institute of Physics.

- **Evidence of follow-through.** CS2 and CS5 (**PIM**) indicate sustained and continuing links to a group of companies, and the research interaction for CS6 (**PIM**) was revitalised in 2012 via the monitoring of an undergraduate placement student with QinetiQ. Falle (**AGFD**), through the spin-off company *Mantis Numerics*, has built and retained contacts with companies, such as British Gas and the National Grid, with the latter of whom a nascent impact CS is developing on the pipeline transport of dense-phase carbon dioxide to sequestration sites.
- **Response to opportunities.** New potential for impact and applications has been generated on two fronts. First, existing members of the unit have expanded their research interests, particularly in **AGFD**, **MBM** and **Applied Nonlinear Dynamics (AND)**. Second, research groups **PIM**, **MBM**, **PSMFM** and **AGFD** in the unit have grown through both appointments (some responsive, see **§c**) and restructuring. Starting with the appointment of Schenk-Hoppé to a *Centenary Chair* in 2005, there are now four researchers in the **Financial Mathematics** subgroup of **PSMFM**. Activity in Statistical Bioinformatics was initiated with the appointments of Gilks (2006) and Gusnanto (2007), who work on the statistics of DNA sequencing. Further alertness to opportunities is illustrated by an *Academic Leadership Chair* (see **§c**) in a new (environmental) area within **AGFD**, and by the 2011 appointment of Gosling (**STATS**), who has strong industrial and governmental links and is generating impact potential in toxicological risk assessment and alternative approaches to testing products on animals. Ward (**AND**) was appointed in 2013; he will develop impact through his work (with advertising company Bloom Agency) by the application of complexity science to social media.
- **How the unit supports impact.** General impact *strategy* is described in **§c**. The unit’s workload model encourages staff to develop consultancies by offering financial incentives, study leave and reduced work allocation, e.g. staff with industrial partners for PhD CASE awards are allocated £500 towards research costs upon the student’s satisfactory completion of the first-year, and staff keep the bulk of the proceeds of any consultancy. The unit’s job descriptions currently include a section on *Research, Innovation and Impact* in which, for appointment at level 8 and above, applicants are explicitly required “*To pursue, develop and lead research, innovation and impact*”; as a result, the majority of new appointments since 2005 are of staff with strong links beyond the academic sector. The unit sets high value on public engagement, as evidenced by the study leave allocated to Cooper (**Logic**) as chair of the international advisory committee for the Turing Centenary year. The unit’s academics link with industrialist participants in both the annual *KT Industrial Inverse Problems Workshop* and the *Leeds Annual Statistical Research Workshop*.
- **Institutional facilities and resources.** The University of Leeds supports outward-facing research on three fronts. First, its *Research and Innovation Services* has the remit to maximise the impact derived from research programmes, and to provide faculty-level administrative and legal support for external consultancies. Second, 14 *sector-facing hubs* (supported by £2.85m from the HEIF) were formed in 2011 to align the University’s research capabilities with external sectors. Third, the University has an EPSRC-funded *Impact Acceleration Account* of £2.32m (2012-15) to “enhance delivery of knowledge exchange”. The unit’s impact maps onto hubs covering *Actuarial Maths (PSMFM)*, *Systems Approaches (MBM)*, *Energy Leeds*, *Climate & Geohazards (AGFD)* and *Polymers & Soft Matter (PIM)*, and a nascent project on biomolecular modelling (**PIM**) plans to disseminate software through the *Digital Innovation Technologies* hub. The unit has a vital share in the University’s *High Performance Computing* facility (see REF5, **§d**), which has been central to



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research in the **PIM**, **AGFD**, **MBM** and **PSMFM** groups, and has fed directly into CS3. Impact often arises through inter-disciplinary links within the University, made possible by the breadth of the University's research activity. Examples include the KTP between the **PSMFM**, Leeds University Business School and Yorkshire Bank that has led to CS4, and the strong interactions between **PIM** and Physics that have fed into CS5 and the *DYNACOP* network (see **Training Networks** above).

### c. Strategy and plans

**Strategy.** In 2009 the unit extensively restructured its research groups to make them more outward-facing and, during the REF period, job descriptions have contained specific reference to “*the pursuit and development of impact*”, and “*participation in knowledge transfer*”. A consequence of this strategy is that 10 of the 16 REF-period appointments (see below) were made in areas having strong potential for short-to-medium-term impact beyond academia. To encourage the creation of external links, in 2010 the unit introduced financial incentives for CASE awards; it also offers teaching relief for consultancies and stresses the importance of impact during staff Annual Academic Reviews, annual Staff Review & Development Scheme interviews and mentoring meetings, via which staff are systematically urged to create and respond to opportunities. This strategy realigned the research of **AGFD** (towards GFD) and **AND** (towards complexity science).

The unit has both an *External Advisory Board* (EAB) and an *Impact Advisory Group* (IAG). The EAB comprises internal researchers and external senior representatives from Deloitte, Teach First, Aon Hewitt, The OR Society, Bionnovel, National Nuclear Laboratory, Bloom Media, Mazars and Industrial Mathematics KTN. It meets biannually to consider both research impact and strategies for employability. The unit is thus ensuring that its research is advised by feedback from both the EAB and the industrial supervisors of its placement students (see **§b**). The EAB's remit includes the encouragement, nurturing and facilitation of future impact-generating activities within the unit. The IAG comprises the Director of Research, Placement Coordinator, Knowledge Transfer Coordinator and Impact Coordinator: its remit is described in **Plans** below.

Central to the unit's recent plans to enhance impact is a new *Academic Leadership Chair*, Bokhove (**AGFD**, 2012), funded by the University as part of its £23m strategic investment in academic leadership: Bokhove, together with Griffiths (**AGFD**, 2008) and Tobias (**AGFD/AND**), are building the unit's capacity to create impact in environmental sciences through their collaboration with the Met Office, with whom a recently initiated project will combine fundamental research on multi-scale processes in fluid models to improve numerical weather prediction. Additionally, Azaele (**AND/MBM**, 2012), Evans (**PIM**, 2012), Ward (**AND**, 2013), and Rodosthenous (**PSMFM**, 2013) will strengthen groups in research areas augmenting the unit's developing impact via, respectively, medical mathematics, statistical mechanics, complexity science and financial mathematics.

**Plans.** The unit's impact activities are coordinated by the IAG, who will: identify opportunities and external links for industrially and commercially funded research collaborations; coordinate such links with appropriate members of the unit; advise the unit's Management Group on possible areas for future appointments; coordinate *Impact Away-Days*; develop a new seminar programme of non-academic speakers. Incentives will continue to include reduced workload-allocation benefits for those involved in impact, potentially leading to study leave. The above-mentioned financial incentives will encourage follow-through and closer interactions with companies. The unit's participation in, and coordination of, three ITNs (see **§b**) will enhance its potential for interdisciplinary industrial contact; **PIM** is partnering a fourth ITN (*SUPOLEN*) from October 2013. Potential collaboration between **MBM** and complexity science (**AND**) has been identified to encourage alignment with the burgeoning areas of biodiversity/ecosystems. The unit will be a partner from April 2014 in 2 EPSRC Centres for Doctoral Training; these will create new research collaborations with industrial partners (~20 in Fluid Dynamics) and other UOAs (see **REF5 §b**).

### d. Relationship to case studies

**Present and Future Case Studies arising from the unit's approach.** The unit's 2009 restructuring (see **§c**) was partly designed to re-group staff whose research had the maximum potential for impact. This resulted in the creation of the **PIM** group, which has authored 3/6 of the unit's CSs (CS2, CS5 and CS6). The current CASE awards (see **§c**), particularly **AGFD**/Met Office and **AND**/Bloom Agency, have strong potential to lead to future impact CSs. Research is being nurtured for future CSs in drug synthesis, cardiac-risk assessment, characterisation of explosives, toxicological risk assessment, and immune-system modelling in health and disease.