

**Scottish Industrial Networking Initiative in Mathematical  
Sciences (SINIMS) Workshop**

***Applications of Mathematics in  
Food and Agriculture***

**Monday 25<sup>th</sup> February 2002**

International Centre for Mathematical Sciences  
14 India Street, Edinburgh EH3 6EZ

**Delegates:**

Dr Alan Archibald	Roslin Institute
Dr David Burt	Roslin Institute
Ms Tracey Dart	ICMS
Dr Ian Forrest	Canongate Technology Ltd
Prof Gavin Gibson	Heriot-Watt University
Dr Chris Glasbey	Biomathematics and Statistics Scotland (BIOSS)
Dr Ralf Jacobs	Mathematics, Strathclyde University
Prof. Robin Knops	Heriot-Watt University
Prof. Andrew Lacey	Heriot-Watt University
Ms. Christine Manson	Simply Organic Ltd
Prof. Sean McKee	University of Strathclyde
Dr Paul Moseley	Smith Institute
Dr David Nicoll	Canongate Technology Ltd
Dr Yiqi Qui	Mathematics, Heriot-Watt University
Dr Richard Smullen	BioMar
Dr Heather Tewkesbury	Smith Institute
Dr Dave Waddington	Roslin Institute
Mr Andrew Waugh	Heriot-Watt University

Delegates will be referred to by their initials.

**Programme:**

- 10:30 Registration / Coffee
- 11:00 Welcome & Introduction to the Smith Institute Faraday Partnership (Paul Moseley)
- 11:25 Mathematics in the Food Industry – An Industrial Perspective (Heather Tewkesbury)
- 12:05 Applications of mathematics and statistics in Food and Agriculture (Gavin Gibson)
- 12:40 Examples of Problem Solving in BioSS (Chris Glasbey)
- 13:15 Buffet Lunch
- 14:00 Fast prediction of Equilibrium pressure of dissolved CO<sub>2</sub> (Ian Forrest)
- 15:00 Tea
- 15:15 Production Technology for Salmon Feed (Richard Smullen)
- 16:00 The potential for mathematics in the Roslin institute (Alan Archibald)
- 16:50 Concluding Remarks (Paul Moseley)
- 17:00 Close

## Meeting Notes

1. PM welcomed attendees to the workshop and introduced the programme for the day (see above). He explained that the objectives for the day were:
  - to provide information for industrialists about the idea of Faraday Partnerships in general, and in particular, the Smith Institute Faraday Partnership.
  - to provide an overview of the range of applications of mathematics in the food and agriculture industry over the last 30 years
  - to listen to industrialists and provide academics with some ideas of the type of problems which are important in the food industry

PM then gave an introduction to Faraday Partnerships (FPs) and their principles. These evolved from a series of government white papers and investigations into maximising the potential of the UK research base for the benefit of industry, with specific attention being given to the industrial sectors identified by Foresight as of strategic importance to the UK economy. A full list of FPs is available on [www.faradaypartnerships.org.uk](http://www.faradaypartnerships.org.uk). The Faraday 'principles' are:

- To promote active flows of people, industrial technology and innovative business concepts amongst the science and technology base and industry
- To promote the partnership ethic in industrially relevant research organisations, business and the innovation knowledge base
- To support core research that will underpin business opportunities
- To promote business-relevant postgraduate training, leading to lifelong learning.

PM also spoke briefly about the Smith Institute Faraday Partnership, and the way it aims to promote the use of mathematics and computing in industry with the aid of its team of Technology Translators (including PM and HT). The Smith Institute covers the whole of the UK, and is in contact with a large network of academics interested in industrially motivated mathematical problems.

Some funding routes were highlighted including the Engineering and Physical Sciences Research Council (EPSRC) CASE and post-doctoral research awards, TCS (Teaching Company Scheme), LINK (several companies and universities collaborating) and SMART. Details of CASE awards which the Smith Institute have available to allocate are available on [www.smithinst.ac.uk/news](http://www.smithinst.ac.uk/news).

PM described some of the current activities of the Smith Institute, involving 30 projects with 70 companies and 25 Universities.

A number of forthcoming events were also highlighted:

- Flexible Photovoltaics – in collaboration with TechniTex, INREB and EPPIC Faraday Partnerships, 21<sup>st</sup> March, Cambridge
- Applications of Mathematics in Oil and Gas, 11<sup>th</sup> March, ICMS
- Applications of Mathematics in Semiconductors, 24<sup>th</sup> April, ICMS
- 43<sup>rd</sup> European Study Group with Industry (ESGI), 2-5<sup>th</sup> April, Lancaster University (further details are given at [www.smithinst.ac.uk/projects/study\\_groups](http://www.smithinst.ac.uk/projects/study_groups))

People requiring further details on these events should contact HT or PM, at the addresses given at the end of this report.

2. HT spoke about an industrial perspective on mathematics in the food industry and made the point that relatively straightforward mathematics can be used to solve 90% of industrial problems, and that industry may need to invest in mathematical research in order to gain the extra 10%. HT's experience in the food industry was through a total of 5 ½ years working for Cadbury's (the first 3 of these was on a PhD at Birmingham University's School of Chemical Engineering), and as such, the main part of the talk was about a case study on modelling the heat transfer in chocolate solidification. The model included thermo-physical properties, which are difficult to evaluate for many instances in the food industry. The key to accurate prediction of the temperature of solidification of chocolate lay in using a full description of the specific heat capacity and latent heat of chocolate at different cooling rates in the model. Allowing chocolate to melt in the mouth and noting the cooling (resulting from the extra energy required to change phase) demonstrated the effect of latent heat. Once the validated model was within accuracy limits of the experimental temperature measurements, the model could then be used for predicting temperatures in new shapes,

sizes and types of chocolates (e.g. 12kg bar, 5g sweet). Mathematics could also be used in analysis of other physical processes, market fluctuations, product design etc. HT then elucidated on current and planned Smith Institute projects in the food industry, including mixing in Chewits, baking and crusting, bubble growth in crumpets, food sorting, microwaving, flow and crystallisation in scraped surface heat exchangers and design of a novel milk flow meter.

3. The emphasis of GG's talk was on the use of stochastic (or inference) models on agriculture and animal feedstuffs. His examples included the following:
  - 3.1. Aerobic deformation and listeriosis of silage: when a silage bale is tightly packed, there is no oxygen in it and the pH drops. However, if a hole is formed by some means, deterioration in the quality of the silage develops, due to gas diffusion and local microbial growth. The pH also rises as a result of the microbial activity. The silage goes through a hazardous stage, during which it appears to be safe but in fact contains listeria. Animals eating this hazardous silage may be affected by listeria. Following the hazardous stage, the silage is spoiled, and will not be eaten by animals. A model was developed to look at listeria growth, gas diffusion and pH change in silo bales, giving information on the hazardous silage which is difficult to identify otherwise.
  - 3.2. Viral disease of citrus trees; the citrus tristeza virus is spread by aphids, and affects citrus trees by the decline of yield over a number of years. For this reason it is tempting to leave them, although infected trees then act as a source of infection for other healthy trees. The spread through orchards of this disease was inferred by modelling background threat of disease and local spread (neighbouring trees).
4. CG explained that the work at BioSS covers nutrition, dairy, environment, crops and diseases at a number of centres around the country. A number of examples were given, including:
  - 4.1. Varadapt software for predicting crop growth and yield for particular varieties in specific geographic locations, with specified soil types from an extensive database. This uses a Bayesian model, incorporating expected and random events to model the function of the different parameters.
  - 4.2. Sensory experiments: saturated experimental design was shown for a particular example of 8 samples, A-G binary factors. Exploration of a potentially large sample space can be optimised using statistical techniques.
  - 4.3. CT scanning of sheep: farmers want fast growing and lean sheep, so a method of determining fat: muscle ratio in sheep was shown. The sheep is scanned in a CT scanner, then the image studied for areas of fat and muscle. In particular, a line is drawn which separates areas of fat and muscle. CG has worked on algorithms to find this line automatically, as manual identification is time consuming. The image is "unrolled" using a transformation from polar coordinates, and then it is searched for areas of high correlation with a template describing the expected image on each side of the line. An algorithm to find the shortest path through the areas of high correlation has proved successful in imitating the manual line detection.  
Further information is available at <http://www.bioss.ac.uk>
5. Canongate Technology manufactures a number of devices for online measurement of various parameters. One of those parameters is dissolved CO<sub>2</sub>, for the brewing and liquid processing industries. The measurement itself requires the value at equilibrium of the response to a vacuum forced on one side of a membrane. The problem is that customers increasingly require real time measurements, and cannot wait for the 15 minutes taken to reach that equilibrium. The rate of diffusion is a function of the area and depth of the interface, and pressure (which is itself a function of temperature, time and dissolved CO<sub>2</sub>; this is then a function of the rate of depletion of CO<sub>2</sub> which is related to the fluid velocity past the sensor). In other words, it is difficult to model the system based on the physics, so instead an alternative method is sought to work out the equilibrium pressure in ~30 seconds. First and second derivatives have been used to calculate the equilibrium pressure and they do decrease the time to 4-5 minutes, but the noise generated is significant so a heavy moving averages technique was employed to reduce this. The second derivative also overshoots the equilibrium pressure before levelling off. They would like to know if there's a better (quicker and noise tolerant) way to predict the equilibrium pressure. CG suggested using a linear regression on early data points to predict the end point, but this would require

a set of calibration curves which are unique (i.e. one to one mapping between early measurements and end points). IF would also like to be able to account for temperature changes in the fluid as this is a real effect seen in processing but affects the measurement. Much discussion followed over tea!

6. RS from BioMar talked about the production of extruded feed for farmed salmon. In these products the balance between protein and lipids is important as that determines the texture of the fish, a measure of consumer preference. In the 1980's the food conversion ratio was of the order of 2.5kg feed returns 1kg fish, but now it can be as high as 0.8kg (concentrated) feed returning 1kg fish. RS went on to describe the production process of the feed, including silo storage of the ingredients, weighing, grinding and mixing, preconditioning, extruding, drying, oil addition, cooling, packaging and delivery. Questions exist about most stages in the process, for example, how do particles flow in the silo? How can the proportion of air be better controlled (if it is too high, the pellets will float instead of the required sinking)? How do the extruder settings relate to the texture of the output, given certain input conditions? Is it possible to predict glassification and melting in the extruder? How can variability in ingredients be accounted for? How can the product in the driers be spread evenly to reduce variability in density and moisture content? How can the oil addition be controlled so that leakage from the finished product doesn't occur? What is the best way of scheduling customers' requirements for packaging (e.g. 25kg vs 1 tonne bags)? BioMar have chosen the marketplace that has relatively high raw material costs with the reward of low risk of product failure, but they still see variability in the raw materials, and want to know what to measure in order to analyse the data and be able to then predict the effect that the variation will have on the process.
7. AA spoke about functional genomics at the Roslin Institute, the farm animal biotechnology research centre, where genetics is the core discipline, although several branches of genetics are studied. One of the main aims of the Roslin Institute is to identify genes and understand better genetic control – in humans there are 30-40,000 genes, each with an on/off control which gives rise to a great deal of uncertainty and fuzzy data. In quantitative genetics, the traits of interest are the quantitative ones that show some continuum in performance. Using animals such as pigs in breeding experiments gives some insight into human genomics as the similarities between pig and human genes can be exploited, while selecting highly selected populations. AA said that the tools for data analysis currently available were not up to the job of making sense of the data, and there is a vast amount of data from which useful information could probably be gleaned. Yet the identification of genes for particular traits is unlikely to be the end of the story, rather the beginning. The challenge presented is to capture, verify, handle, store and present data before analysis even begins.
8. PM summarised the day's presentations thanked the speakers.

*Contact details:*

**Paul Moseley**

Smith Institute  
C/o ICMS  
14 India Street  
Edinburgh  
EH3 6EZ  
Tel: 0131 220 1777  
Email: [pmosley@maths.ed.ac.uk](mailto:pmosley@maths.ed.ac.uk)

**Heather Tewkesbury**

Smith Institute  
PO Box 183  
Guildford  
Surrey  
GU2 7GG  
Tel: 07815 096 711  
Email: [Tewkesbury@maths.ox.ac.uk](mailto:Tewkesbury@maths.ox.ac.uk)

*Some useful websites:*

[www.dti.gov.uk](http://www.dti.gov.uk)  
[www.epsrc.ac.uk](http://www.epsrc.ac.uk)  
[www.faradaypartnerships.org.uk](http://www.faradaypartnerships.org.uk)  
[www.foresight.gov.uk](http://www.foresight.gov.uk)

[www.ma.hw.ac.uk/icms](http://www.ma.hw.ac.uk/icms)  
[www.sbs.gov.uk/smart/](http://www.sbs.gov.uk/smart/)  
[www.smithinst.ac.uk](http://www.smithinst.ac.uk)  
[www.tconline.org.uk](http://www.tconline.org.uk)