Future Manufacturing with Mathematical Sciences Workshop

1st-2nd May 2012
Manufacturing Technology Centre, Coventry

BACKGROUND

The Engineering and Physical Sciences Research Council (EPSRC) wishes to promote their Mathematical Sciences and Manufacturing the Future interface, and in particular to promote novel mathematics inspired by manufacturing research challenges, as well as new manufacturing research which is underpinned by novel mathematical sciences.

It has been identified that there is limited interaction between the two academic communities and also recognised that there would be vast potential benefits if the interaction between manufacturing researchers and mathematical sciences researchers were enhanced.

EPSRC intends to commit up to £4million to fund an upcoming Manufacturing the Future with Mathematical Sciences call, which is expected to be issued in the early summer of 2012. In order to shape this call for proposals, a workshop took place over a 24-hour period from Tuesday 1st May to Wednesday 2nd May 2012 at the Manufacturing Technology Centre in Coventry.

The workshop was jointly organised by EPSRC, the Industrial Mathematics Knowledge Transfer Network, and the High-Value Manufacturing Catapult Centre. The workshop's stated purpose was to generate new thinking and ideas for research at the interface of the mathematical sciences and manufacturing; to raise mutual awareness between manufacturers and mathematical sciences; and to engage with manufacturing and mathematical sciences researchers.

The participants in the workshop were drawn from large parts of the current UK landscape; however, it is appreciated that they did not cover all of the mathematical sciences and manufacturing landscapes. It is hoped that the workshop and call will start to build longer term relationships between the manufacturing and mathematical sciences communities, encouraging future thinking rather than solutions that solve immediate problems in industry today.

FORMAT OF THE WORKSHOP

The workshop began with each participants giving a two-minute introduction on their work. They were asked to highlight their expertise, current activities and challenges they have, alongside areas of interest for collaboration. This revealed a wide range of different mathematical interests, including modelling, optimisation, statistics, uncertainty analysis, scientific computing, dynamical systems and inverse problems.

Many of the academic delegates had existing links with industry, whether by virtue of formal collaborations or of interests in industrially motivated problems. The industrial and manufacturing delegates demonstrated a keen interest to forge links with academic mathematical scientists in several areas, including computational modelling of physical systems, algorithm design for distributed computing, and system-level analysis of manufacturing processes. From the presentations, there appeared to be limited current interaction between the manufacturing and mathematical sciences communities and a recognition that better interaction would help to increase potential benefits.

Following the introductions, the participants were divided into seven discussion groups. Each group was asked to identify five current challenges, knowledge gaps, or research opportunities relevant to future manufacturing. These ideas were then shared with the entire workshop group, and clustered into a set of key themes, following some lively discussion. There was recognition amongst the delegates and EPSRC that the list of challenges that were raised was not exhaustive.

Eight themes emerged from this process (see below). A second round of break-out discussions was held to allow delegates to discuss one or more of the eight themes in greater detail. Each breakout group was asked to address the same four questions in the context of their chosen theme:

- What are the challenges in this area?
- What are the potential benefits to manufacturing?
- What kind of expertise will be needed?
- What will success look like?

Each group nominated a 'theme champion' to guide the discussion and to take responsibility for reporting their findings in a final wrap-up session. These findings are summarised in the remainder of this report (see Appendix A).

OUTPUTS

The eight themes identified by the delegates are summarised in the following list. A fuller explanation of each theme is given in Appendix A.

1. Full life-cycle modelling
2. Optimisation under uncertainty / flexible processes
3. Model integration
4. Data capture and analysis
5. Real-time process control
6. Supply-chain modelling
7. Manufacturability
8. Engagement and knowledge transfer*

* Engagement and knowledge transfer was recognised as a 'cross-cutting' issue. It was one of a number of General Observations that also came out of the initial group discussions.

GENERAL OBSERVATIONS

Several broad observations emerged, in addition to the eight themes listed above:

1. The focus of the workshop delegates was mainly concentrated on 'current' challenges; however, EPSRC would like to look at longer term opportunities and this should be reflected in EPSRC's call for proposals.
2. Interaction between manufacturing and mathematical sciences is welcomed and should continue to be encouraged after the workshop. In particular, manufacturing academics should be encouraged to work with mathematical sciences academics.
3. A greater range of mathematical sciences and manufacturing research is necessary to solve future problems and not just current issues.
4. There is significant scope to harness more areas of pure mathematics in addressing problems on the Mathematical Sciences/Manufacturing interface.

Further to these issues, it was generally accepted that there is currently insufficient engagement between academic mathematical scientists and industry. The uptake of existing mathematical tools and techniques in manufacturing is slow. Larger manufacturing companies tend to have existing links to manufacturing and mathematical sciences researchers, but it is particularly difficult for SMEs to engage.

In order to encourage engagement and further knowledge transfer, it was suggested at the workshop that one or more programmes should be developed to aid this, e.g. more focussed workshops, short visits or longer-term embedding of mathematical scientists in companies.

Increased knowledge transfer will allow manufacturers to rapidly access new ideas, potentially giving them a commercial advantage, decrease their costs, and reduce the risk associated with their processes.

It was identified that the marketing of mathematical sciences within manufacturing should be increased, as well as developing a better understanding of the business climate. In order to do this, it was suggested that there should be greater engagement with industry, particularly with SMEs, and more awareness of important industrial problems within the academic community.

It was noted that these workshop suggestions could be followed up by all researchers through pathways to impact funding on EPSRC grants and also that working with the Industrial Mathematics KTN will help to maximise the impact of their research.

NEXT STEPS

Manufacturing the Future is one of EPSRC's key challenge areas. The next step following the workshop is a call for proposals to encourage the manufacturing community and mathematical sciences community to work together.

The research themes identified in the workshop are ideas to stimulate thinking towards the call and they are not part of the call's assessment criteria. From the workshop and imminent call for proposals, we hope for there to be more collaboration and interaction between the two disicplines, and for mathematical sciences and manufacturing to appear more often together in future standard grant proposals.

EPSRC will continue to explore future possibilities for other methods of engagement and welcome any further ideas which will help to strengthen the relationship between manufacturing and mathematical sciences.

CONTACTS

For further information on the workshop contact:

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APPENDIX A

EXAMPLE RESEARCH THEMES IDENTIFIED

Theme: Full life-cycle modelling	
Challenges	Overall, this is a problem of integration and global optimisation. One needs to be able to assemble and manage hierarchical (and heterogeneous) models and data; to integrate operations in a sustainable, flexible, and reconfigurable way; and to select, organise and control a complex system. Similarities and differences exist between continuous and discrete processes – these should be qualified and handled appropriately. Optimisation of a full life-cycle will require many aspects to be considered, including the evolution of a product family, production, supply chain, servicing, warranties, end-of-life cost, etc.
Benefits to manufacturing	Aside from broad benefits such as increased profitability, sustainability and productivity, full-life-cycle modelling ought to result in more flexible and responsive systems. Furthermore, it should help manufacturers to avoid 'lock-in', and increase resilience to economic or technological changes.
Expertise needed	• Domain knowledge of particular manufacturing processes / products / business / information systems • System organisation theory • Control theory • Statistics • Supply chain modelling / operations research • Data management • Software engineering • Computer science • Discrete mathematics
Definition of success	• Contribution to knowledge and development of system theory, especially of hybrid systems and systems of systems. • Contribution to manufacturing stakeholders in the form of robust operations, sustainability and profitability. • An ambitious, overarching goal would be to introduce a new generation of product life management techniques, and to have them be widely adopted.

Theme: Optimisation under uncertainty / flexible processes	
Challenges	Overall, the goal is to address the trade-off between the robustness and performance of a process. However, any attempt to model a complex system must begin with a careful formulation of the problem. This will often involve multiple objectives, and uncertainty in the system behaviour, making optimisation a difficult mathematical problem. Incorporating a requirement for flexibility into the optimisation will complicate matters further, imposing additional constraints and objectives on the system. Methods for decomposing and synthesising systems should be examined carefully. Developing a standardised procedure that can be applied to a range of different processes and systems will be a key challenge in this area.
Benefits to manufacturing	Optimisation of processes can include economic, sustainability and environmental objectives, so a successful mathematical procedure ought to improve all of these factors. Furthermore, more flexible planning should result in more robust manufacture in the face of economic uncertainty.
Expertise needed	• Statistics • Optimisation / operations research • Computational expertise • Software engineering • Data modelling
Definition of success	• Development of a set of best-practice procedures for process optimisation, perhaps encapsulated by a software toolbox. • A move towards ‘first time right’ manufacturing. • Increased competitiveness in terms of productivity and sustainability. • Greater control of and robustness to uncertainty.

Theme: Model integration	
Challenges	Manufacturing processes are usually comprised of many different sub-processes. Mathematically, each of these sub-processes might be represented by a model. However, a model of the entire system would need to integrate the sub-process models in a consistent manner. Models may be heterogeneous in both scale and type, and there is a need to propagate uncertainty from one model to the next. The mathematical challenges here involve the validation of such complex models and the need to pass discrete/stochastic effects through a chain of models operating at different scales.
Benefits to manufacturing	In addition to matters of profitability, productivity, sustainability, etc., manufacturers should benefit from improved process understanding and control by the introduction of a more modular approach. This may allow for more rapid development of processes for new prototypes or custom-designed products.
Expertise needed	• Stochastic and deterministic modelling • Domain experts • Statistics • Computing • Linked model/software standard (e.g. Open MI) • Uncertainty and uncertainty propagation (e.g. MUCM)
Definition of success	• Evidence of uptake by manufacturers • Emergence of a standardised (flexible) methodology • Industrial validation of processes • Case studies • Increased competitiveness of UK industry

Theme: Data capture and analysis	
Challenges	As sensor technology and computer power and storage capacity increase, manufacturers often find themselves with an overwhelming volume of data, and few strategies for extracting useful information from it. There is a need to develop process-specific and sector-specific tools for data processing, based on dimensionality reduction, feature extraction, data mining, correlation analysis and other techniques. Another challenge is to develop tools for automatic data collection and analysis, ensuring that data is collected and stored in an appropriate, future-proof format.
Benefits to manufacturing	Manufacturing should benefit from insights into collected data. This will feed into several of the other themes (e.g. full-life-cycle modelling and real-time control). In turn, this should lead to higher quality products, and improved productivity.
Expertise needed	• Statistics • Data mining • Machine learning • Signal processing • Image processing • Model reduction • Scheduling/networks • Topology of data • Software engineering
Definition of success	• Meaningful interpretation of data into information • Reliable products based on reliable data • Reliable processes and understanding of rare events

Theme: Real-time process control	
Challenges	As part of a production process, it is necessary to adjust the control parameters in response to quality assessment of completed components/products. In order to do this, one needs to have a good model of the physical/chemical/biological system, an understanding of the important parameters (such as may be gained from a sensitivity analysis), and knowledge of the system state and the means by which to effect desired changes in the finished article. The challenge is to bring together each of these aspects with detailed sensor measurements. Further challenges arise from the need to make measurements without interfering with the process (i.e. solving inverse problems), dealing with response times or lag between cause and effect, and uncertainty in the exact system state.
Benefits to manufacturing	• Increased profitability • More rapid, real-time response to change • More uptime in manufacturing processes • Greater product quality
Expertise needed	• Mathematical modelling • Inverse problems • Statistics • Domain knowledge (process expert, manufacturing) • Numerical analysis • Scientific computing • Software development • Control theory • Measurement/data handling expertise • Optimisation
Definition of success	• Demonstration of fast and reliable solutions • A flexible yet robust methodology for real-time control • Development of a 'menu' of sub-process models

Theme: Supply chain modelling	
Challenges	Supply chain strategies used in today's industry are outdated and are often not fit for purpose. They ought to be tailored to a specific product or process, accounting for the differences between top-down and emergent design, and between tree-like and multiply-connected designs. It is also important to balance timescales and capacity, and to understand the goal of the 'ideal' supply chain. In general, supply chain models should allow greater flexibility and resilience toward uncertainty.
Benefits to manufacturing	Increased productivity in terms of lower costs and shorter turnaround times. Increased robustness in the face of uncertainty.
Expertise needed	• Optimisation (particularly of network topology) • Bayesian networks • Domain knowledge of relevant sector(s) • Uncertainty handling • Game theory
Definition of success	• Development of a unified metric for the performance of a supply chain network • Methods for identifying points of failure • Cross-sectoral learning and collaboration • Introduction of a 'new mathematics of logistics', perhaps based on Bayesian networks

Theme: Manufacturability	
Description	Although this theme was not discussed in detail, it was highlighted that it is important to look to new developments in mathematical sciences (e.g. tropical geometry) and assess their usefulness to manufacturing. Many mathematical scientists do not currently engage with industry, so there is a need to connect with research in these areas and translate new ideas and results into improved design for high-value products and processes.

APPENDIX B

WORKSHOP PARTICIPANTS

NAME		AFFILIATION
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