Pathways to manufacturing seminar series

ANTICIPATING MANUFACTURABILITY NEEDS AND CHALLENGES TO SUPPORT THE PATHWAY TO IMPACT

Key messages from Seminar One

TECHNOLOGY | MANUFACTURING | PRODUCT | MARKET

The first Pathways to Manufacturing Seminar was held at the University of Cambridge's Institute for Manufacturing (IfM) on the 15th of April, 2015. The seminar explored how manufacturability challenges affect the scale-up and industrialisation (pathway to impact) of technical research and development (R&D).

Manufacturability is the capability to produce a technical product in an industrial setting, while meeting particular standards of functionality, cost, quality, and repeatability.

The speakers focused on the value and importance of manufacturability in the development of novel, emerging technologies. Dr Mark Claydon-Smith and Mr David Wright traced the progression of reports that reflect the growing interest of the UK government in the positive economic and social impact of the research it funds (i.e. Cabinet Office, 1993; RCUK, 2007; EPSRC, 2010, 2011), highlighting the policy precident and the importance of manufacturability for the UK's R&D funding agencies. They explored how they have incorporated manufacturability into their portfolio of programmes and into their individual calls for proposals. They also provided examples of where anticipated manufacturability challenges have been considered in successful research proposals and some issues they observed when they were not.

Dr Chris Rider provided specific examples where manufacturability challenges have had a significant impact on the success of research and development projects. One particular example, on the topic of Organic Light Emitting Diode (OLED) displays, demonstrated how manufacturability challenges significantly influenced the technical feasibility, economic viability, and resulting product success. An example was also given that demonstrated how manufacturability considerations are being used to evaluate the viability of a technology development project, based on the functionality it could provide in a product, its competitive positioning, and the manufacturing capabilities required to deliver it – its technical feasibility and commercial viability.

Dr Charles Featherston provided an overview of the Pathways to Manufacturing project, which aims to develop a framework to help researchers become sensitised to potential manufacturability challenges and anticipate some of the challenges they might face.

The seminar drew out a number of broad considerations that might need to be made, the implications of which can have considerable consequences on the manufacturability of technology. These include:

- Defining requirements early
- Defining the competitive position: "performance" vs costs
- Assessing technology system linkages and interactions
- Assessing manufacturing process maturity
  - Assessing the ability to scale-up and its implications

The seminar also highlighted a number of specific questions related to manufacturability that should be considered early in the development of a novel technology. These questions included:

- **Industry-standard processes** – does manufacturing the technology use processes (techniques and equipment) that are known to, and commercially viable in, industry?
- **Process parameter screening** – what process parameters is the technique sensitive to?
- **Process parameter sensitivity** – how sensitive is the technique to each major parameter?
- **Materials options** – what cost and availability issues is the technology and its production exposed to?

The Pathways to manufacturing seminar series, and the Pathways to manufacturing programme more generally, aims to build on these considerations and questions by collecting and consolidating experiences from a broad range of manufacturing researchers and disseminating these to support public and private researchers, developers, and investors.

Speakers

- **Dr Mark Claydon-Smith** – Lead, Manufacturing for the Future, EPSRC
- **Mr Dave Wright** – Head of Manufacturing, Innovate UK
- **Dr Chris Rider** – Director, EPSRC Centre for Innovative Manufacturing in Large-Area Electronics at the University of Cambridge
- **Dr Charles Featherston** – Centre for Science, Technology and Innovation Policy (CSTI), University of Cambridge

Pathways to manufacturing project team:

- **Dr Charles Featherston**
- **Dr Ronan Daly**
- **Dr Eoin O'Sullivan**
- **Yoanna Shams**

OVERVIEW OF THE FIRST PATHWAYS TO MANUFACTURING SEMINAR

Manufacturing is the combination of inputs (materials, equipment, energy, etc.) and processes (techniques and their timing and coordination) to produce outputs (devices, components, products). Manufacturing is essential for the conversion of technical designs, the principles of which have been demonstrated, into products that are deployed (and is particularly important when they are deployed at scale). The requirements (needs and constraints) for manufacturing are intrinsically linked to the nature of the technical principles (the technology) and the device/ component/ product being fabricated (the product) - manufacturing does not exist 'in and of itself'[1]. Manufacturing is a crucial link between concept and market, making it essential in the development and deployment of a novel technology.

Manufacturability is the capability to produce a technical product in an industrial setting, while meeting particular standards of functionality, cost, quality, and repeatability. It depends on the configurational possibilities of inputs, technical designs, and processes used to produce a product. While manufacturing is important in the development and deployment of novel technology, manufacturability is important because it is the ability to produce a technology with (competitive) attributes and costs such that economic value, social value, or both is created.

Manufacturability in R&D

The seminar affirmed that manufacturability needs to be considered early in technological R&D, it even needs to be considered 'from the very beginning'[2]. Such demands mean that there is an 'art'[3] to selecting the right questions to ask, selecting their timing, and realising the implications of their answers. However, it is an art that can (at least in part) be learnt from mistakes made and lessons learnt. Leveraging whatever experiences and resources researchers have, and even those that researchers have as a collective, can be used to help realise economic and social value from technological R&D.

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Considerations of manufacturability issues are difficult for a number of reasons. First, uncertainty prevails in all factors relating to the deployment of technology, and is particularly high at the early stages of development. Particular areas of uncertainty raised in the seminar include the product in which the technology will be deployed and its requirements, customers and markets and their requirements, material availability, design specifics, system requirements, and manufacturing requirements, each of which influences the others to varying degrees, necessitating them to be assessed synchronously.

Second, complexity further complicates the consideration of manufacturability in technology development. Increasingly advanced technological (high-tech) devices and components are being integrated into increasingly complex architectures, creating ever more complex systems. These complex technology systems mean that the technical viability, (technical) functionality, (technical) stability, quality, and economic viability of individual devices and components can have a significant effect on the overall performance of a (product) system. Technical complexity is also reducing the differences between technology development and manufacturing as novel fabrication processes increasingly enable new devices and components to be produced (e.g. processes that 'grow' the material). Increasingly this intertwines considerations of technical challenges and manufacturability challenges. Technical, architectural, and research complexity places increased pressure on defining markets and products for the assessment of the viability of further technical-research, the uncertainties relating to which cannot easily be navigated or allayed.

Lessons

The presentations and discussion at the seminar pointed to some lessons learnt and questions that can be used to understand and assess the manufacturability of novel, emerging technologies. It was generally agreed that the particular lessons identified in the seminar were relevant, and that the manufacturability risks and uncertainties that should be considered evolve and change as R&D progresses. The following five considerations were common themes throughout the seminar and are discussed in more detail below.

- Defining requirements early
- Defining the competitive position: "performance" vs costs
- Assessing technology system linkages and interactions
- Assessing manufacturing process maturity
    - Assessing the ability to scale-up and its implications

Defining requirements (early)

The speakers at the seminar suggested that defining the requirements of the product and the (subsequent) requirements of the device or component and its manufacturing processes is a paramount concern for assessing the manufacturability of a device or component and a product. This relates directly to product and market uncertainty. Defining the product and potential markets first, at least to some degree, with reference to the technology's specific functionalities and specifications, reduces some uncertainty about the requirements placed on manufacturing. The dependency of manufacturing requirements on product requirements and technical specifications is an intrinsic consequence of the role of manufacturing in technology development and deployment. It was stressed in the seminar that manufacturability can't be meaningfully thought about until a clearly defined application has been defined.

Defining the competitive position: "performance" vs cost

Defining the requirements is made more complicated by the competitive context. Incumbent technologies can have significant benefit over novel technologies, not least because of their existing capital investments and their established, reduced level of uncertainty (because of established knowledge). Potential substitute products (or technologies) further threaten the competitive positioning of a novel product (or technology). The subsequent functionality, quality, design, and cost requirements to be competitive place further demands on a product and technology and thus on the requirements of its manufacturing processes. These need to be matched with the feasible yield (and waste, scrap-rate, etc.), which influences the costs of producing the technology. Furthermore, the functional benefit has to outstrip the costs (and yield) obstacles. The uncertainties surrounding the performance-cost (functionality, quality, design vs input

[1,2,3,4] Direct quotes from the speakers at the seminar

costs, yield, waste, scrap-rate, etc.) assessment can further deter adoption, indicating that the functionality benefit or cost benefit has to be significant to justify the risk, especially when, as suggested in the seminar, '"performance" has to sometimes be sacrificed to increase manufacturability'[4].

Assessing technology system linkages and interactions

Bound in with both these issues are the system-level considerations and constraints relating to the technological system (product system) into which technological-devices and –components are integrated. These considerations and constraints include the (inter-)connections between devices/components and the critical role particular devices and components play in delivering the primary and secondary functions of the product (the robustness and redundancies of particular system architectures). These system considerations further complicate the manufacturability of a product as the lowest quality, least reliable, and shortest lifetime of the constituting devices and components and their interconnections define the quality, reliability, and lifetime of the overall product system.

Assessing manufacturing process maturity

The current state of technical and market knowledge is often used as a rough proxy to assess the risk of a novel technology and its manufacturing processes (often assessed as 'known to firm', 'new to firm', 'new to world'). In the seminar, a particular point was made highlighting how the risks related to devices and components that incorporate novel technologies can be considerably reduced when industry-standard processes can be used to fabricate them. These standard industrial processes are used because they meet a certain criteria, including performance, repeatability, and cost (including waste) and their incumbent status can reduce capital and skill development investment needs. The uncertainty related to novel industrial processes do not necessarily meet these criteria and hence increase technical and economic (financial) risk.

In both cases it was suggested that particular attention to some key process tests can be used to conduct an early and quick estimate of the manufacturing viability of a technology. Such process tests included temperature variation, humidity variation, repeatability tests, and lifetime tests.

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Assessing the ability to scale-up and its implications

Scale-up refers to the increase of production yield by a dimensional unit, including number, length, area, or volume. Scale-up is an often referred to example manufacturability challenge and the presentations and discussions at the seminar stressed that this was often not an easy task. An example provided in the seminar was of doubling the area of material applications in the fabrication of a device, which led to material homogeneity issues and resulted in significant and unacceptable variations in product performance. The seminar highlighted that scale-up also often leads to far greater, even prohibitive, costs. While, scale-up is a common challenge in manufacturing, it was suggested in the seminar that the scale-up challenges different technologies face vary significantly.

Extracting a 'checklist' for establishing the manufacturability of a technology

Along with the lessons/ considerations above, the seminar drew out some preliminary questions that need to be asked to establish the manufacturability of a technology. These included:

1. **Industry-standard processes** – does manufacturing the technology use processes (techniques and equipment) that are known to, and commercially viable in, industry?
2. **Process parameter screening** – what process parameters is the technique sensitive to?
3. **Process parameter sensitivity** – how sensitive is the technique to each major parameter?
4. **Materials issues** – what cost and availability issues is the technology and its production exposed to?
5. **Functionality disadvantages** – what are the functional disadvantages of using particular processes (i.e. impact on resulting performance, lifetime, etc.)?

Broad competitive positioning considerations

Manufacturing also needs to consider the competitive positioning of the technology and products it aims to produce because, as outlined, its requirements are determined to a large part by balancing the requirements of the product and the specifications of the technology – in short it links technology to the competitive market place. The seminar highlighted the following two broad competitive positioning considerations:

6. **"Performance" advantages** – what advantages might the new technology bestow in a possible (early) application over current technologies?
7. **"Cost" position** – based on current knowledge and possible (early) applications what are the cost advantages of the novel technology?

Panel Session discussion topics and implications

The seminar concluded with a panel session, where questions from the attendees generated a discussion, which was led by a panel made up of the speakers and was managed by Dr Ronan Daly (FIAM, IfM), but in which all those attending participated. The discussion topics covered at length included:

- **Partnering** – how partners should be selected (criteria); how to generated interest from potential partners (how should be approached); the obstacles to partnering; the differences in goals and practices of academic and industrial partners; and research related issues arising from market dynamics, partner 'lock-in', intellectual property.
- **Responsiveness** – how to react to particular manufacturability assessment findings and when action should be taken.
- **Deployment, commercialisation, and moving out of the research-base** – the implications of manufacturability for the commercialisation of technology and their deployment in products, including: commercialisation models (patenting, licencing, spin-outs/ start-ups, etc.); models for making intellectual property publicly available; timing of commercialisation; competitive considerations; and motivations for commercialisation.

Manufacturability and the Pathways to Manufacturing programme

The above manufacturability considerations have, at least partially, been integrated into more formal processes or organisational structures to support the scrutiny of the manufacturability of novel technologies. The US Department of Defense's (DOD) Manufacturing Technology Programme (ManTech), for example, has developed and maintained a manufacturing readiness and risk management criteria as part of the US Defense Acquisition System. Another example is Bell Laboratories (Bell Labs), where the market focus of its R&D programmes and organisational structure that facilitated interaction between researchers and those applying their research sensitised researchers to manufacturability consdierations and potential manufacturability issues.

However, niether of these examples are completely useful for researchers and developers outside these organisations. The DOD's criteria lacks a market perspective, since it is the customer and defines product requirements and volumes early. The Bell Labs example provides a useful (process) guide about how researchers can sensitise themselves to manufacturability issues, but because it was a consequence of organisational structure it is not replicable by all technology researchers and developers. Furthermore, any specific manufacturability risk factors that should be considered have remained within Bell Labs.

The Pathways to Manufacturing programme aims to leverage elements of the above examples and combine these with the academic literature, lessons from experienced manufacturing researchers, and lessons from a lab-based case study to advance understanding of the key manufacturability challenges facing emerging technologies. The project will build on the DOD manufacturability risk criteria and adapt it for non-defence-specific research. It will also use the approach of using the knowledge and experience of those planning to apply the research and those further 'downstream', which was common in Bell Labs as well as elsewhere, to help assess risk the criteria. It will establish a framework that can be used as a tool by researchers to support risk assessment.

The framework will aim to:

- sensitise researchers to specific manufacturability risk factors they might need to be concerned with
- help/guide researchers to identify to whom they might talk to assess particular risk factors
- provide some experiences and practices outlining the potential implications of particular risk factors
- provide some experiences and practices outlining how particular risk factors have been overcome in the past
- provide a timeline for when these factors need to be considered, assessed, and potentially directly addressed

The framework will do this by providing a checklist of questions that should be asked by researchers at particular stages of development. It will also provide some case studies highlighting the implications of some some manufacturability challenges and how some of these challenges have been overcome in the past.

The Pathways to Manufacturing programme is being undertaken by the Centre for Science, Technology and Innovation Policy (CSTI) and the Fluids in Advanced Manufacturing (FIAM) research group, both at the Institute for Manufacturing (IfM).

ABOUT THE PATHWAYS TO MANUFACTURING SEMINAR SERIES

The Pathways to Manufacturing Seminar Series is one of the knowledge transfer mechanisms of the Pathways to Manufacturing Programme. The series aims to collect and share experiences of issues related to the manufacturing processes, manufacturing systems, and industrial system that affect manufacturing capability experienced during the development and deployment of novel technologies. The series aims to reach out to university- and industry-based researchers and developers, their partners, and their funding agencies and investing organisations to expose and sensitise them to what categories of issues they might scan for when developing novel technologies.

Upcoming seminars

Second Seminar on Pathways to Manufacturing
Case studies and experiences: lessons learned in the development and deployment of emerging technologies
October, 2015

Third Seminar on Pathways to Manufacturing (TBC)
Experiences and reflections: expressing and exemplifying the findings of the pathways to manufacturing programme
December, 2015

FOR PROGRAMME INFORMATION

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ABOUT CSTI

CSTI, led by Dr Eoin O'Sullivan (eo252@cam.ac.uk), carries out applied research exploring what makes national innovation systems effective at translating new science and engineering ideas into novel technologies and emerging industries.

ABOUT FIAM

FIAM, led by Dr Ronan Daly (rd439@cam.ac.uk), carries out applied research exploring novel manufacturing processes for emerging technologies and emerging industries.

Acknowledgements
We like to acknowledge the support, financial and otherwise, of the Collaboration Skills Initiative of the Engineering Department. We would also like to acknowledge The Gatsby Foundation for their financial support.