WINTER 2017/18 | Issue 8

Institute for Manufacturing REVIEW

The next production revolution

- National policy responses
- Industrial lasers
- The productivity paradox and business model innovation
- Factories of the future
- Design for additive manufacturing
- Rethinking supply chains
- The skills challenge

UNIVERSITY OF CAMBRIDGE
Department of Engineering

IfM | MANAGEMENT TECHNOLOGY POLICY

INSTITUTE FOR MANUFACTURING: IfM

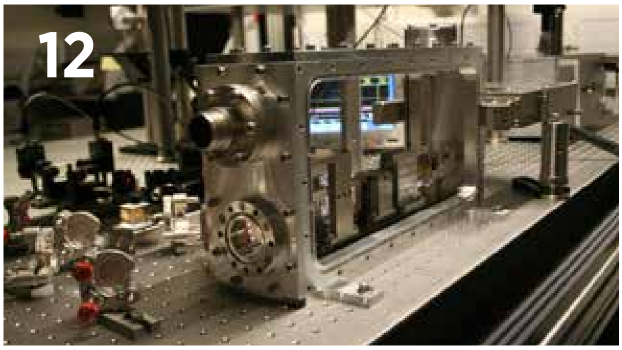
The IfM is part of the University of Cambridge's Department of Engineering. With a focus on manufacturing industries, the IfM creates, develops and deploys new insights into management, technology and policy. We strive to be the partner of choice for businesses and policy-makers, as they enhance manufacturing processes, systems and supply chains to deliver sustainable economic growth through productivity and innovation.

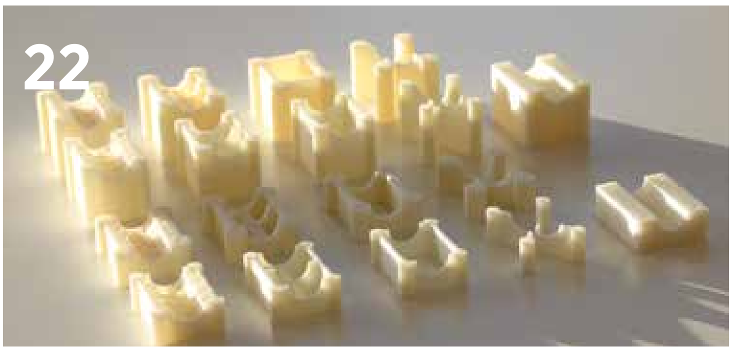
IfM EDUCATION & CONSULTANCY SERVICES LIMITED: IfM ECS

IfM ECS is owned by the University of Cambridge. It transfers to industry the new ideas and approaches developed by researchers at the IfM. Its profits are gifted to the University to fund future research activities.

Cover image: © Yoanna Shams.
This optical image shows layers of iron oxide nanoparticles printed on a silicon wafer. The carrier fluid evaporates to leave unique coloured fringes that relate to the varying thickness of the solution in different regions. Yoanna is a PhD student in the IfM's Fluids in Advanced Manufacturing research group which examines chemical and physical phenomena of polymeric, biological and nanomaterials when exposed to advanced fluid-based manufacturing techniques.

Contents





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www.ifm.eng.cam.ac.uk/research/ifm-review

The next produc

For this issue of the *IfM Review* we have borrowed the OECD's concept of 'The Next Production Revolution' as a useful way of reflecting on some of our major research areas. Rapid advances in production technologies, particularly when allied with the digitalisation of manufacturing, promise a huge range of both opportunities for national governments and individual firms - as well as the challenges that disruption inevitably brings.

Professor Bill O'Neill (page 12) describes some of the cutting-edge research into production processes taking place at the IfM and how this work is beginning to translate into significant commercial activity. But, as both he and Dr Eoin O'Sullivan (page 8) discuss, the ultimate winners – in national terms – will not be those countries that develop the novel technologies but those that find a way to overcome the manufacturability challenges they present and do so at scale. Governments are, therefore, in something of a race to put in place new approaches to manufacturing innovation.

However, while developing the right R&D programmes and institutions is clearly going to play a pivotal role in determining who wins and who loses at the national level, firms also need to think about how they can most effectively leverage the new technologies. Dr Chander Velu (page 16) cautions that new technologies in themselves do not, for example, bring about significant productivity improvements – it is only through business model innovation that productivity benefits of new technologies can be fully realised.

Factories clearly have an important role to play in the next production revolution. But the whole notion of what constitutes a factory and where we can and should apply 'factory thinking' is starting to change profoundly. Professor Duncan McFarlane (page 19) argues that during this time of major recalibration, driven by a whole host of new digital technologies, it is more important than ever that firms develop their automation strategies with a clear sense of strategic direction.

And as technological developments bring us ever closer to new, distributed ways of making things, we see a concomitant reappraisal of supply chain thinking. Dr Jag Srai (page 28) reflects on the annual Cambridge International Manufacturing Symposium, at which speakers and delegates considered the impact of new manufacturing paradigms on supply chains against the backdrop of changing perceptions and expectations of globalisation.

How do companies keep their eyes on the horizon and ensure that they are the ones who spot and seize the opportunities that are right for their business? We can all think of organisations that failed to see the threat a new technology posed to their business. Dr Letizia Mortara (page 25) explains why having a systematic technology intelligence system in place is not just 'a nice to have'.

Another consequence of this unremitting pace of change is the impact it is having on the workforce. Governments, industry and education providers like us are faced with a considerable challenge if we are to equip people at all

ction revolution

stages of their working lives with the knowledge and skills they need.

A practical example of this is considered by Dr James Moultrie (page 22) in the context of additive manufacturing. If industrial designers are to exploit additive manufacturing's capabilities to the full they need to go back to the drawing board and completely rethink their design principles. The lack of shared knowledge in this area seems to be a significant factor inhibiting the widespread take-up of additive as a mainstream production technology.

But the skills question is a much broader one, as Tom Ridgman (page 30) explains. At Cambridge over the last 50 years we have pioneered project-based, problem-solving approaches to learning which have served our engineering students well, we hope. (Certainly, our interview with ACDMM alumnus Andrew Hawes on page 34 suggests we haven't been getting it too badly wrong.) But it is vital that we don't get complacent particularly in these revolutionary times. Now more than ever we need to ensure that our students can thrive in a complex and constantly changing workplace. In many ways, knowledge is the least important part of their education. They can find all that at the touch of a button. But knowing what to do with it - that's what will set them apart. And it's our (very rewarding) job to help them develop their already considerable capabilities in this regard so that they can become the next generation of manufacturing leaders and innovators.

I hope you enjoy this issue of the *IfM Review*. If anything particularly catches your eye and you would like to discuss it further, please do get in touch. We are always delighted to hear from you

Best wishes,

Tim Minshall
Head of IfM and
Dr John C Taylor Professor of
Innovation

IfM news

Tim Minshall appointed as inaugural Dr John C Taylor Professor of Innovation and new Head of IfM

In September, Dr Tim Minshall was appointed the Dr John C Taylor Professor of Innovation, a new post that builds on the University of Cambridge's strengths in science, engineering and entrepreneurship. In October, Tim also became Head of the IfM taking over from Professor Andy Neely. Tim remains Head of the IfM's Centre for Technology Management.

The new professorship has been made possible thanks to a generous donation of £2.5million from Dr John C Taylor OBE, one of the most successful British inventors of the last 50 years. The Chair will enable Tim to build on his strengths in innovation and technology management, both in the University and in the UK more broadly.

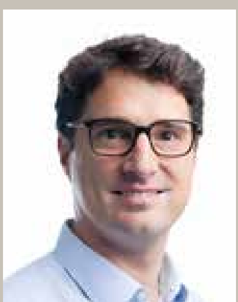
Tim joined the IfM in 2002 as a member of the Centre for Technology Management. He established his own research group within the Centre focusing on technology-based enterprises and became a University Reader in Technology and Innovation Management in 2013.

He has also been a recipient of the University's Pilkington Prize, awarded to its most exceptional teachers. Most recently, he has been leading research into the industrial adoption of 3D printing and has been part of the team developing the UK's National Additive Manufacturing Strategy.

Tim became Deputy Head of the IfM in March 2017 when Andy Neely was appointed the University of Cambridge's Pro-Vice-Chancellor for Business and Enterprise, leading the University's strategy to deepen its engagement with industry and commerce, and the wider enterprise economy in the region.

Professor Tim Minshall and Dr John C Taylor

Other appointments



Senior Research Associate with the Cambridge Service Alliance, **Dr Florian Urmetzer**, has been appointed as Operations Director (part-time) for the IfM's taught MPhil in **Industrial Systems, Manufacture and Management (ISMM)**. He retains his post in the Service Alliance.

David Hogan has joined **IfM ECS** as a Senior Industrial Fellow. David is a Chartered Engineer, a Fellow of the Institution of Engineering and Technology (IET) and a Chartered Quality Professional with over 40 years' engineering and business experience in the Royal Navy, BAE Systems, The Engineering Council and Nuvia Ltd.

The Next Production Revolution

In May, the OECD published *The Next Production Revolution: Implications for Governments and Business*, an assessment of the medium-term economic and policy implications of new and emerging production technologies.

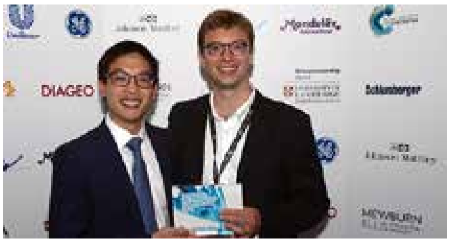
Dr Eoin O'Sullivan, Director of the IfM's Centre for Science, Technology and Innovation Policy (CSTI) and Dr Carlos López-Gómez, Head of IfM ECS's Policy Links Unit, wrote the chapter 'An international review of emerging manufacturing R&D priorities and policies for the next production revolution'.

Read the article by Eoin O'Sullivan on page 9. You can find the whole book at: bit.ly/2jZdzUg

Christoph Mueller (right), Chief Digital and Innovation Officer, Emirates Group at Cambridge Service Alliance Industry Day

Bridging to new service technology

At the Cambridge Service Alliance annual Industry Day Conference in October, keynote speakers from Emirates airline, Alibaba, IBM and Thales joined forces with the CSA team to discuss the development of digital service strategies and how they can create value now and in the future.



Next generation nano-battery paves way for electric bus revolution

In June a University of Cambridge spin-out, Echion Technologies, was awarded second-place and £10,000 to help commercialise its invention in the Energy and Environment category of the annual Royal Society of Chemistry competition.

Echion Technologies was founded by Dr Michaël De Volder, Head of the IfM's NanoManufacturing group and Department of Engineering colleagues, Dr Adam Boies (Division of Energy, Fluids and Turbomachinery) and Jean de La Verpillière (NanoDTC Translational Fellow).

The Echion team hopes to fuel an electric bus revolution with its novel hybrid nanomaterial that could herald the third-generation of high-performance automotive batteries.

Intelligent assets for the infrastructure of the future

Professor Duncan McFarlane (Head of the Distributed Information and Automation Laboratory) and Ajith Parlikad (Head of Asset Management) have co-authored an ICE (Institution of Civil Engineers) Guidance Paper on how new technologies will transform the infrastructures of the future.

Intelligent Assets for Tomorrow's Infrastructure looks at how advances in sensing and data management have the potential to transform the way our key infrastructural assets perform throughout their lives, enabling them to identify problems and solve them themselves. The Guidance Paper sets out the team's vision for how we should be managing these assets and outlines how new technologies can help us do so.

IfM news

Revolutionising the UK's internet provision

The IfM is a partner in a £5 million research collaboration that is set to revolutionise the UK's internet infrastructure.

IfM's expertise in the Internet of Things (IoT) and cyber physical systems will be a key contributor to developing the next generation internet (5G) in a national digital telecommunications infrastructure project. This network will not only deliver faster speeds, it will also enable the internet to be used in completely new ways with, for example, driverless cars, smart homes, telemedicine, precise remote control of drones and virtual reality.

Jointly funded by the Engineering and Physical Sciences Research Council (EPSRC) and telecommunications company BT, the Next Generation Converged Digital Infrastructure project brings together multidisciplinary researchers from the University of Cambridge (IfM and the Judge Business School), Lancaster University (project lead), University of Surrey and University of Bristol.

IfM's Distributed Information and Automation Lab (DIAL) will help make a radical change in the way networks perform and are maintained by bringing its expertise in IoT and cyber physical systems, together with its research within the Cambridge Centre for Smart Infrastructure, to the project.

MET student in battle for LEGO supremacy

Manufacturing Engineering Tripos (MET) student James Gard and fellow Cambridge Engineering student and LEGO enthusiast, Jamil Jami, competed in a Channel 4 series over the summer in a bid to become 'LEGO Masters'.

The Clare College duo displayed their engineering skills, imaginations and creativity 'in a battle to be crowned masters of the brick'. Some spectacular builds – including an impressive 'explorers' chair with an integrated lever system – saw them through to the fourth and final episode where they were knocked out just before the final task.

James said: "Our structures knowledge is always useful in helping us to create some clever load-bearing models, and mechanics lectures have definitely helped with some of our fancy moving model designs."

IfM ECS relaunches membership scheme for SMEs

In July, IfM ECS relaunched its membership scheme. The scheme gives small and medium-sized companies access to strategic, technical and innovation expertise from the IfM.

Member companies get free places for two employees on our SME Member training courses and research update events. They also benefit from an account manager who devises a programme for them which typically includes access to IfM research and to student projects. Consultancy is also available at reduced rates for members.

Find out more at: www.ifm.eng.cam.ac.uk/ecs/about/membership/smemembership

Student study tour to Japan

The IfM's Manufacturing Engineering Tripos (MET) final year students visited Japan for their two-week overseas research project.

The aim of the project was to investigate the digitalisation of manufacturing and the progress that is being made in Japan. The students visited three areas: Tokyo, Fuji and Kyoto, and met with 16 different organisations. Organisations visited include Fanuc (industrial robotics), Omron (automation), Daikin (air conditioning) and the Ministry of Economy, Trade and Industry, as well as many others.

Each year MET students fund raise for and organise their own overseas research project. In 2018 they will be heading to California to investigate emerging technologies in the manufacturing space. To find out more about sponsorship packages, contact Jenny Shepherd (js2160@cam.ac.uk)

Transforming Indian agriculture: IfM key partner in tackling major global challenge

The IfM's Centre for International Manufacturing (CIM) is part of the Cambridge team working with Indian scientists to bring about a second Green Revolution. This project – TIGR^{2}ESS – is one of two Cambridge-led research collaborations receiving support from the UK government's Global Challenges Research Fund.

The first Green Revolution in the 1960s brought about a massive increase in crop production in India and other developing countries. TIGR^{2}ESS is a collaboration between UK and Indian researchers which seeks to address the big question – how to bring about a second Green revolution in India. The Cambridge side of the project is led by the Cambridge Global Food Security initiative which brings together research from a wide range of disciplines. The CIM team will be using its supply chain mapping and modelling tools to analyse the end-to-end production, processing and distribution of food. This will help make supply chains as resource efficient and – from a resource stewardship perspective – as transparent as possible in order to minimise waste and environmental impact.

For more information, read the article at www.bit.ly/2niNoZJ or contact Dr Jag Srai: jss46@cam.ac.uk

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Policy Links supports UK-Japan policy dialogue

In September, Policy Links convened a UK-Japan manufacturing and innovation policy workshop, bringing together senior officials from ministries and innovation agencies in the UK and Japan. Held in Tokyo and supported by the Science and Innovation Network (SIN), the workshop set out to support the advanced manufacturing stream of the UK-Japan Industrial Policy Dialogue, established in a joint statement by Prime Ministers Theresa May and Shinzo Abe in August 2017.

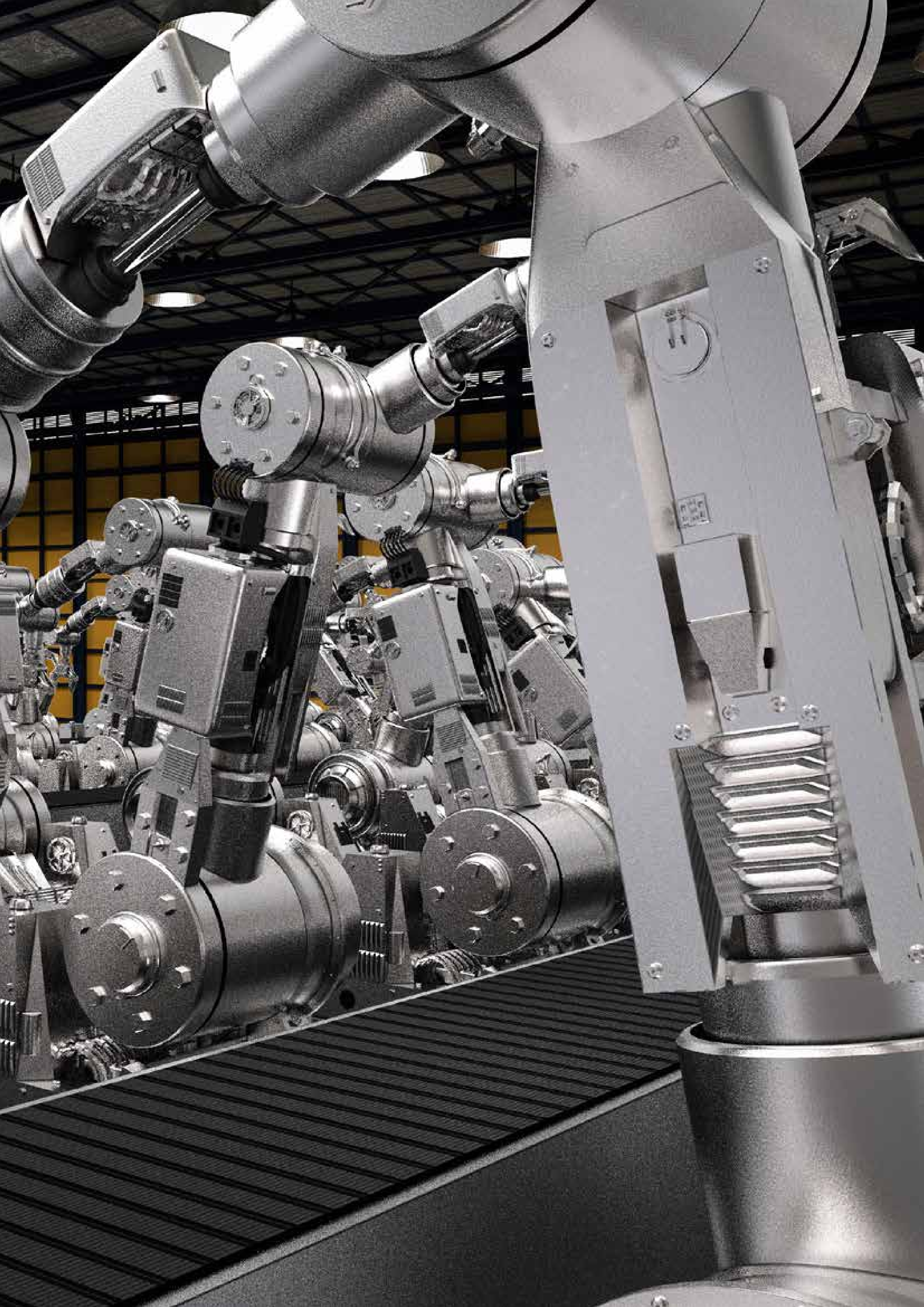
Clare Porter, Head of Manufacturing at the Advanced Manufacturing and Defence Business and Science Group, Department of Business, Energy and Industrial Strategy (BEIS) said: "The workshop identified practical next steps to increasing the depth of understanding of UK and Japan advanced manufacturing capabilities including opportunities for sharing technology road maps and user cases".

Become an IfM member

The IfM has two membership schemes that aim to build closer, long-term relationships between companies and our wide range of expertise, and to provide tailored support.

Corporate membership: for access to research-based strategic, technical and business expertise, geared to the needs of large international companies.
SME membership: for access to capability development for small and medium-sized companies, plus discounts on IfM services.

For more information: **www.ifm.eng.cam.ac.uk/membership**



Manufacturing innovation: the next production revolution

Director of the IfM Centre for Science, Technology and Innovation Policy (CSTI), Dr Eoin O'Sullivan, outlines the implications of an emerging 'next production revolution' and explores how governments around the world are starting to prepare for it.

Manufacturing is changing. New technologies are radically altering not only how we make things, but how we innovate. As manufacturing systems, technologies and innovation activities become more complex, distributed and interdependent, policy makers around the world are looking for new ways to ensure national competitiveness for the so-called 'next production revolution'.

What is the next production revolution?

New technologies such as industrial digitalisation technologies (Internet of Things, Big Data, cyber-physical systems, for example), biomanufacturing, nanomanufacturing, advanced materials and novel production technologies (such as 3D printing), are expected to reshape production and drive disruptions across entire value chains. The OECD coined the term the 'next production revolution' to describe the impact these new developments will have on manufacturing systems.

What does it mean for governments and industry?

Change on this scale will present many challenges and opportunities). Some areas which have already been identified as needing attention include the need for new infrastructure, new skills, new business models, and new efforts to ensure cyber-security, privacy and customer protection. In particular, there will be a need to define and invest in new manufacturing R&D priorities, programmes and institutions.

The increasingly complex 'systems' nature of manufacturing poses a significant challenge to policy makers. Manufacturing in the twenty-first century cannot be understood by analysing individual sectors or technologies alone. Many of the most valuable manufactured products are themselves complex systems, made up of different technological components, produced by advanced ICT-enabled process technologies, and reliant on complex, interdependent supply networks. The 'digitalisation of manufacturing' is not only disrupting how manufacturing firms do business, it promises to reshape national manufacturing systems and redefine sources of national competitive advantage.

New digital technologies are radically altering the ways countries make things, and even how they innovate new products and services. In an era of ever more complex, distributed and interdependent supply chains, new ICT and data analysis tools offer new ways to organise and manage manufacturing. Furthermore, these systems are not only responding to rapid technological change, they are also being shaped by powerful social and economic drivers such as changing demographics, climate change and energy security. They also rely on the availability and combination of factors that are

To find out more about our research in science, technology and innovation policy contact:
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vital to the rest of the economy: labour, knowledge, natural resources and capital.

To add further to the complexity, product and process R&D is also becoming increasingly dispersed and interdependent. If nations do not develop strong connections between their science and engineering research base and their industrial manufacturing activities, the risk is considerable. Not only could they lose their ability to translate these new technologies into high value production within their economies, they also risk losing the ability to innovate the next generation of high value manufacturing products. To compete effectively, therefore, national economies require industrial-innovation systems that can respond to emerging high-value industrial opportunities with the right combinations and clusters of technological R&D, skills, institutions and infrastructure.

Three key themes which are emerging in many national manufacturing policies and advanced manufacturing R&D strategies responding to the 'next production revolution' are: convergence, scale-up and paying increased attention to national economic value capture from manufacturing innovation.

Convergence

Many future high-value products and manufacturing systems will depend on a range of technologies, such as advanced materials, nanotechnology, biotechnology and novel ICT. The combination and integration of these technologies has the potential to enable a range of new applications and new markets. Some of the most potentially disruptive technologies are based on convergence between science and engineering research domains. Quantum technologies - combining digital IT and advanced materials - and synthetic biology - combining digital IT and biosciences - are both examples of convergence.

Convergence is also occurring between manufacturing systems, and industry sectors. It is the convergence between all of these technologies and systems that is likely to drive the next production revolution.

In designing advanced manufacturing research programmes and initiatives, policy makers need to be aware that convergence is opening new manufacturing R&D opportunities and challenges, with increasing scope for innovation in manufacturing and more diverse ways in which value can be captured from it. The European Commission's research programmes addressing 'multi-KETs' (multiple key enabling technologies) are examples of explicit efforts to pursue new manufacturing R&D opportunities driven by convergence.

Scale-up

The system complexity and relative immaturity of many of the key technologies driving the next production revolution also pose significant challenges for the manufacturing scale-up and industrialisation of new products. These converging technologies may be integrated in ways that offer new product functionalities and/or improved performance. However, it may be difficult to maintain these features during production at industrial scale using conventional manufacturing tools and processes.

Policy makers need to be aware of the manufacturability challenges associated with the scale-up of disruptive science-based technologies, which may require new R&D-based solutions and novel tools, production technologies and facilities. Investments in applied research centres and pilot production facilities focused on taking innovations out of the laboratory and into production are common approaches to tackling these challenges.

The attention given to scale-up is likely to increase due to the competition and the pace of technological change which is creating a sense of urgency among policy makers. They are seeking to reduce the time between R&D-based discovery and the deployment of advanced manufacturing innovations and to facilitate rapid scale-up and market penetration of advanced manufacturing technologies in industry. This in turn is driving the need to demonstrate more efficiently the technical feasibility and manufacturability of products embodying novel technologies.

The need to bridge the gap between knowledge generation and the commercialisation of advanced product and manufacturing-process innovations is high on the international policy agenda. Some of the UK's Catapult Centres, for example, were established to address scale-up challenges in areas such as high-value manufacturing, cell therapy and satellite applications and increase the scale, speed and scope of commercialisation. The Catapult network

This article draws from the chapter 'An international review of emerging manufacturing R&D priorities and policies for the next production revolution', authored by Dr Eoin O'Sullivan, Director, (CSTI) and Dr Carlos López-Gómez, Head, Policy Links Unit, IfM ECS, in *The Next Production Revolution: Implications for Governments and Business* published by the OECD 2017.

has been earmarked for a 'growing role' in helping to commercialise new and emerging technologies under the UK government's new Industrial Strategy.

Capturing economic value from the next production revolution

Unsurprisingly, many OECD countries are looking to the next production revolution for new opportunities for value capture. For instance, there is interest in hybrid production technologies and systems able to produce customised products at mass production prices. Increased automation and the application of advanced ICT across manufacturing systems, together with the convergence of manufacturing technologies are offering new possibilities to increase factory productivity and reduce the length of supply chains.

New production technologies that combine multiple production steps can, for example, significantly reduce production times. Hybrid machining centres are a good example of this; they can perform laser heat treatment in addition to a machining process during the same operation, vastly reducing changeover times. There is also considerable interest in the potential of internet-based businesses to capture value from the online delivery of goods and services and the interactions with customers.

Such approaches are particularly important in the context of the growing demand for individualised products and may allow certain high-value production activities to be retained in high-wage economies. Germany's Cluster of Excellence Integrative Production Technology for High-wage Countries, for example, is looking at a combination of approaches that will make it possible to keep German high-value manufacturing operations at home.

Emerging policy responses to the next production revolution

The next production revolution is likely to be characterised by the convergence of technologies, the integration of industrial systems, and the blurring of traditional science and engineering R&D domain boundaries. In this context, manufacturing research and innovation may also change significantly.

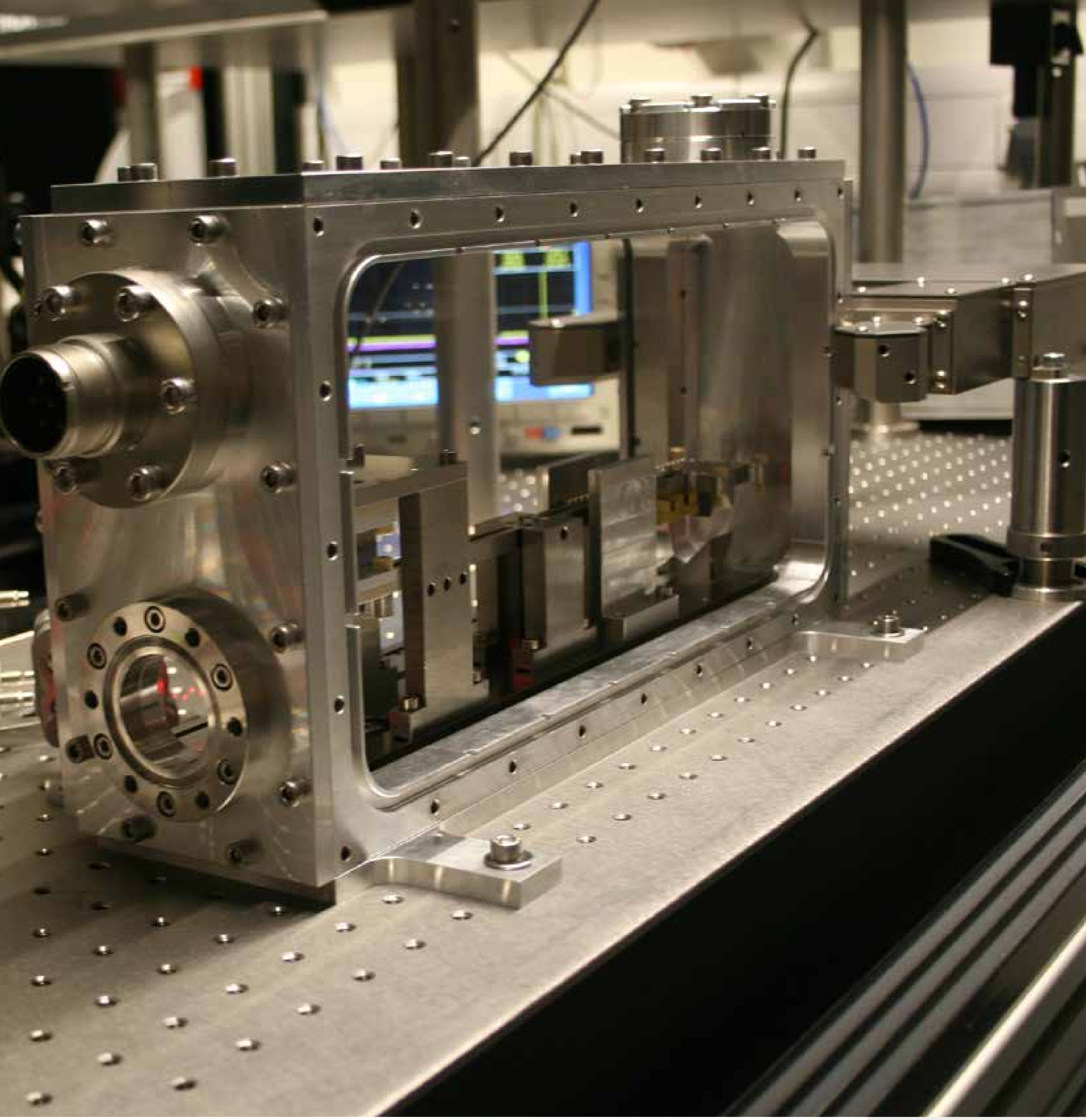
Government-funded manufacturing R&D institutions and programmes around the world are responding to these changes in a number of ways, including increased attention to innovation-related activities beyond basic R&D. We are seeing a greater focus on prototype demonstration to technology developers, application demonstration to users, skills training and workforce development and supply chain development. There seems to be increasing investment in shared research and innovation spaces such as demonstration facilities, pilot lines and test beds of various kinds. There is also an increased focus on 'grand challenges' with R&D on topics such as sustainable manufacturing, nanomanufacturing and energy storage.

In summary, there appears to be growing consensus that a new manufacturing revolution is coming. New converging technologies and integrated application systems are radically altering not only how we make things and how services are delivered, but also – critically for the manufacturing and engineering management research community – how we carry out manufacturing R&D. Many governments are looking to ensure national competitiveness by developing new types of R&D programmes and institutions expressly to facilitate the rapid scale-up, demonstration, diffusion and deployment of 'next production revolution' technologies.

Dr Eoin O'Sullivan

Short course for policy makers

From Research to Economic Impact: Designing Modern RTO Strategies, 12–13 April 2018
Find out more at: bit.ly/2AGtP42


Experimental set-up in the Centre for Industrial Photonics. Credit: Nadeem Gabbani and Krste Pangovski

The revolution starts here

Professor Bill O'Neill, Head of the Centre for Industrial Photonics, leads IfM research into the development of industrial lasers. He discusses the current role that precision industrial lasers and other technologies are playing in increasing capability and productivity in manufacturing.

The production of parts has traditionally been done through cutting, milling, machining, forging, casting and welding. The industrial laser revolution that began in the 1960s is now a standard method of digitally-driven production that offers high flexibility, reliability and speed. Most manufacturing now uses some form of laser technology to undertake some of these traditional tasks. However, it is the evolution of laser technologies for precision engineering applications at the nanoscale that is one of the key developments driving the next production revolution.

Lasers – together with other disruptive production technologies that have been on the horizon for some time – are now starting to have a real impact on manufacturing. Digitalisation is increasing the connectivity between people, products, processes and the supply chain. Combined with the rapid development of artificial intelligence, self-learning machines and robot technology, it heralds a new period for production.

These technologies – particularly production technologies that are flexible, reconfigurable and driven by digital descriptions such as CAD/CAM systems – have been slowly evolving over the past 20 years. We are now are in a position where products (both their physical and material properties) can be described in the virtual space very well. We have the digital data that describes a product and machines that can be manipulated to either cut-out one million identical parts or cut-out one million unique parts without any disadvantage in terms of cost or time.

Supersonic laser deposition

The goal of our solid state supersonic laser deposition research is to dramatically increase metal deposition rates for coatings and 3D-components. Supersonic laser deposition applications include:

- Titanium coatings for aerospace and biomedical components
- Hard-facing for the tool manufacturing industry
- Repair of engineering components
- Corrosion protection layers
- Metallisation of non-metallic surfaces

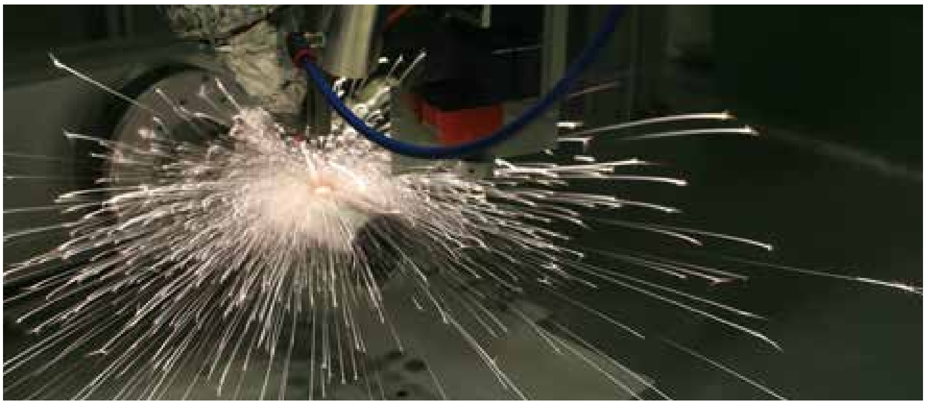
We are developing metal coating techniques using this new form of additive manufacturing to deliver multi-material systems that offer nanoscale functionality in macroscale components, such as higher lubrication performance and increased wear resistance for applications such as dry-film lubrication in gearboxes. When you reduce the need for liquid film lubrication, you make power transfer through it more efficient.

We are also working on enhancing the lifetime of blade components in steam and gas based turbine generators, creating significant cost savings for the energy generation sector. One of the problems with conventional metal additive manufacturing technologies is that deposition rates are incredibly low, between 100cc and 200cc/hr. New developments of our supersonic laser deposition process will, we think, be able to achieve around 5000 to 7000 cc/hr, even for hard-to -work materials like titanium. We are making great progress in depositing materials with a near machined edge quality, which means products of all sizes can be built incredibly quickly. This technology is showing great promise in a wide range of sectors and is the principal technology being developed by the University spin-out company Laser Fusion Technologies Ltd.

Our research focuses on three key production processes – industrial lasers, additive manufacturing and nanomanufacturing.

Lasers

We are researching laser-based techniques to cut, weld, melt, machine, structure, pattern and transform materials. There has been huge growth in laser technologies, particularly precision laser processes, since the early 2000s, with the invention of the high-power fibre laser. Fibre lasers are very robust and, because the technology is used in many R&D outputs from the communications industry, they have developed very quickly. The high-power laser industry has been able to piggyback on the billions of dollars of investment made in the communications sector to develop its own variants of high-power lasers.



Supersonic laser deposition on a tube

To find out more about our research in industrial photonics, please contact:
Professor Bill O'Neill
Email: wo207@cam.ac.uk

Within the research context, we are trying to make sure that laser technologies play their part in the next production revolution by enabling automated manufacturing and increasing flexibility to change on demand. We can digitally drive all of our toolsets, they can be monitored and measured, so lasers can be easily incorporated into factory networks. The laser industry by itself only has a capital value per year of around $10 billion, but it supports $2 trillion worth of products. For example, the smart phone would not exist in its current form without the laser. Even the data it relies on is moved around the world by lasers. And whether it is a low- or high-power laser, the toolset has a vital role to play in the future of production.

Additive manufacturing

Additive manufacturing (AM) is a hot topic. Although it is a technology that we have been working on for 30 years and we have seen its application in a number of different areas, there are two growth areas in which AM is a potential game-changer – biomedical and aerospace. Following 30 years of investment in techniques, materials, machines and processes, AM is now in a strong commercial position and we are now seeing companies like GE and Stryker investing billions of dollars to put AM technologies at the centre of their production operations.

In the biomedical sector, where the production of metallic implants still uses traditional techniques such as forging, there is a dramatic move towards exploiting AM technologies. Although additive capabilities are becoming more widespread, machining will still have an important part to play. The objective is to make a better part, with greater functionality such as enabling bone to grow and fuse with metal implants, leading to products with a higher value and greater patient benefits.

Nanotechnology

Nanotechnology is another area that has the potential to change dramatically the future of production over the next 10 to 15 years. Nanomanufacturing involves the manipulation of nanoscale materials to make novel materials with superior qualities. We have a number of research projects with the US Air Force using laser-based techniques to develop improved nanoscale surface features for anode materials that can withstand intense electrical fields, and minimise outgassing of hydrogen in high energy microwave devices. We use picosecond laser technologies (ultra-short laser pulses) with in-process Raman microscopy to pattern graphene layers and create defects for greater functionalisation of graphene.

A new suite of pulsed laser deposition technologies is being developed to create nanoscale layering of materials for the direct writing of functional electronic devices. Our research team is also working with Dr James Elliott in the Department of Materials Science and Metallurgy to further the manufacturing technology

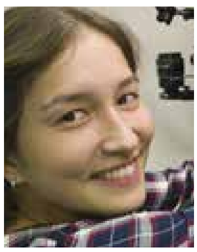
Additive manufacturing transforming medical care

Medical implant specialist Stryker Corporation has been collaborating with Professor O'Neill over the past 20 years to develop AM technologies for the production of biomedical implants.

Stryker has been developing the technology to additively manufacture surgical devices like knee implants, tibial baseplates and titanium posterior lumbar cage spinal implants. The metal implants have an outer porous structure that resembles spongy bone tissue and encourages accelerated osteointegration to connect the implant with the patient's own bone.

This work led to the expansion of Stryker's manufacturing and R&D facilities. In May 2017, Stryker officially opened its custom-built Additive Manufacturing facility at Cork in the Republic of Ireland. The new facility has become the hub for furthering Stryker's R&D into AM techniques for creating medical devices for patients.

Using a combination of AM and robotic surgery, patients may one day be in the operating theatre having cancer removed, while at the same time an implant is being additively manufactured next door to perfectly fit the space left after removal of the cancerous bone.



See page 33 for PhD Spotlight on CIP's Katjana Lang and her work on nano-scale superconductors.

Stryker's Tritanium® PL (Posterior Lumbar) Cage, a hollow, rectangular implant built using Laser Rapid Manufacturing method. Credit: Stryker

for gas phase production of carbon nanotube (CNT) fibres and films. These new nanoscale materials show substantial promise, with significant improvements in mechanical, and electrical performance compared to conventional materials such as carbon fibre.

Commercial expectations from new technologies

Greater demands and expectations are being placed on UK manufacturing to support economic growth. The UK government's Industrial Strategy White Paper is pushing investments in new materials, new technology and new manufacturing processes. Now our leading research organisations are being challenged to match our research successes with new levels of commercial exploitation.

To meet this challenge, we need Innovation Centres at key university sites across the country to accelerate the transition of research outputs from the lab bench, through to alpha and beta scale demonstrators within an Innovation Centre, and onwards through to Catapults and ultimately the industrial base. This is the model that we are working on at the IfM and across the University of Cambridge more broadly.

Improving productivity

These new technology developments will only lead to a new production revolution if we increase productivity and drive down costs. Production innovation should result in more innovative and competitive products and services. We can only do that if we maintain quality, or guarantee quality. Quality assurance systems, and new process technologies combined with sensors and control systems must be integrated to produce higher performing production operations.

The future research focus of the Centre for Industrial Photonics is to develop new directed energy-based production technologies such as lasers, ion beams, or particle beams, with a high level of intelligence and machine learning. We must take the expert out of the production equation, and build expertise into the machine, and into the manufacturing system, and thereby offer industry higher performance and true 'right first time' production operations.

Triathlon Tritanium Cementless total knee system. Credit: Stryker

Professor Bill O'Neill

Solving the **productivity** paradox

through **business model innovation**

New digital technologies are supposed to bring us unprecedented efficiencies and new opportunities for value creation. So why has the productivity of major economies been slowing down over the past ten years? And in spite of the recent (small) upswing in our productivity figures, why does the UK perform so much worse than its peers? What's going on, asks the IfM's Dr Chander Velu, and might it have something to do with business models?

In productivity terms, the UK currently lags around 35% behind Germany, 30% behind the US and 9% behind Italy. These figures make such startling reading that they distract us from the fact that the rest of the world is not doing very well either, most notably the G7 economies. Particularly perplexing is that the sectors contributing most to the slowdown seem to be the most intensive users of information and communication technologies.

This has had analysts scratching their heads and hypothesising possible causes. The aftermath of the financial crisis continues to have an impact on markets. We also know that the inexorable rise of digitalisation has brought with it a number of challenges as well as opportunities: its take-up is being hampered by a lack of skills – particularly in the UK - and while some firms are performing disproportionately well there remains a long tail of SMEs that are struggling to adopt the new technologies. These could all be factors but is there something else going on?

One area that is ripe for further exploration is the need for business model innovation alongside technological innovation. We know that the introduction of new technologies does not - by itself - translate into productivity gains. One of the lessons we have learnt from the industrial past is that when electric motors first replaced steam engines in the US there was very little initial improvement to productivity. It was only when firms completely changed their business processes and corresponding business models that the technology had a significant impact on productivity – and that process took 30 years. Is something similar going on with the so-called 'Fourth Industrial Revolution'?

Studies have shown that firms which place too much emphasis on efficiency (and not enough on meeting their customers' needs) inhibit their potential to innovate their business model.

Is how we measure productivity part of the problem?

Productivity is measured at two different levels. Analysts either look at the activity levels within individual firms to improve the efficiency of their processes or they take an economy-wide view to measure economic growth. There are two problems with this approach. Firstly, the firm-level measures focus on improving the efficiency of existing business models and not the effectiveness of the business models themselves. It looks at how value is created and captured – and how efficient a firm is at doing that – and not at the potential changes to the business model in order to deliver new customer value propositions. This is a major shortcoming when trying to understand the productivity of a business model – it needs to take account both of the firm's and its customers' perspectives. Studies have shown that firms which place too much emphasis on efficiency (and not enough on meeting their customers' needs) inhibit their potential to innovate their business model.

The second problem arises from the flipside of that scenario. Digital technologies have, in some cases, so radically transformed the way products are made and sold that it makes productivity for national income growth difficult to calculate. For example, the 'old' business model in which a firm creates value and then transfers it to the consumer has been totally disrupted by firms such as Uber where individuals – in this case, drivers – play a key part in the value creation. In other sectors, different models have emerged in which, for example, content is given away free to the consumer with a view to charging corporate customers for advertising.

Towards a new framework for business model innovators

There is definitely something interesting going on with business models. On the one hand, a lack of innovation may be stifling the productivity gains new technologies can offer. On the other, where business model innovation has taken place, it could be affecting our ability to measure productivity properly. If firms are to solve the productivity paradox – and policymakers are to support them in their endeavours – they need to better understand and measure the productivity of their business models and be able to change them accordingly.
Our research programme is working on ways of doing exactly that.

Digitalisation, as we know, is having an impact on virtually every aspect of manufacturing, from 3D printing to last-mile logistics. In order to explore the relationship between business model innovation and productivity and develop some tools to measure its efficacy, we have chosen intelligent automation as a case for illustration. Intelligent automation has the potential to underpin business

To find out more about our research in business model innovation, please contact:
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model innovation in a whole range of different ways. (See table right.)

The possibilities are evident. To date, however, there has been very little research into how business model development can be institutionalised alongside technology development in order to improve productivity.

Distributed manufacturing and the rise of distributed ledger technologies

If we think there are ways intelligent automation can enable business model innovation, we can also see the potential for wholesale disruption of the conventional manufacturing model in which products can be manufactured close to the consumer. Distributed manufacturing presents enormous opportunities for increasing productivity but there are also some significant barriers in its way. If the making of products is delegated to third parties, how can the IP owner ensure they get paid and how can they ensure that the product is manufactured at the right quality and is compliant with any regulations? Some of these issues can be solved by using distributed ledger technologies, a broad swathe of complementary technologies including bitcoin and other cryptocurrencies, blockchain, distributed consensus, smart contracts and the associated security-related technologies.

In the future, it is highly likely that many consumer appliances will be IoT-enabled and capable of checking their own quality, integrity and intellectual property. If the appliance is connected to a distributed ledger this data could be recorded and made accessible – securely – to a range of users who would then be in a position to develop new business models and hence drive productivity improvements.

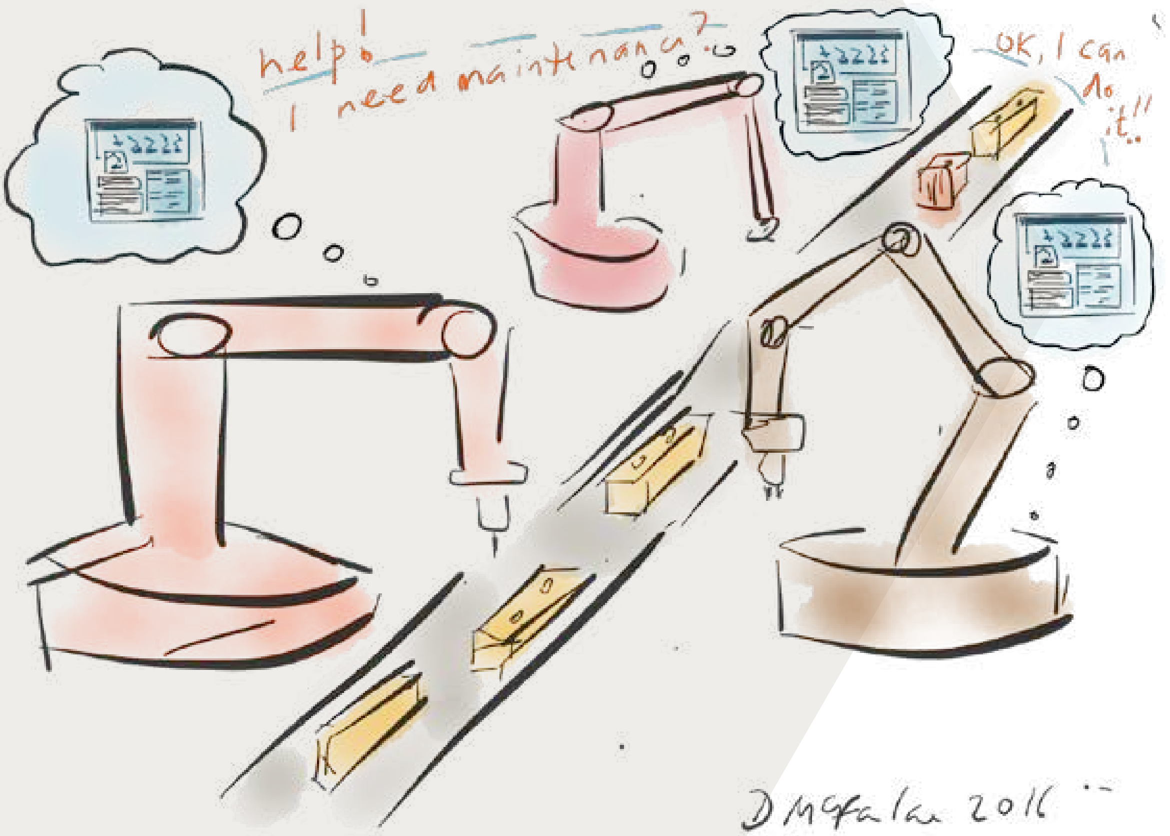
Sector	Old business model	New business model	Future business model
Manufacturing	Factory automation	Predictive analytics anticipates customer demand and adapts production processes accordingly	Distributed manufacturing which combines intelligent products with additive manufacturing at the point of sale
Distribution	Online shopping	Predictive analytics recommends products to customers and anticipates orders	Fully automated fulfilment systems including the use of autonomous delivery vehicles
Sharing economy (eg Uber)	Taxi service	Predictive matching algorithm matches customers and drivers and adapts pricing to match demand and supply	Autonomous taxis

The designers of the appliance - as well as monitoring usage and managing their IP - could check their products' performance and collect data that could be used to improve future designs. Product comparison firms could rate aspects of performance such as energy use and noise levels. Sales firms could value an appliance remotely by looking at its age, usage and repair history and set up an auction. Regulators could check that the appliances meet safety standards. Custom design firms could develop bespoke parts and appliances to meet the needs of particular demographics, such as the elderly or visually impaired. Rental companies could rent them, offering servicing and upgrades. These connected technologies can also help reduce environmental impact. With over two million tons of waste electrical equipment generated annually in the UK alone, any reduction in waste through better repair and recycling would be helpful.

In its recent Industrial Strategy White Paper, the UK government emphasised that solving the productivity paradox is critical if the UK is to increase the value of its manufacturing and deliver economic growth. The development of digital technologies is creating plenty of opportunities to improve productivity but until firms are able to re-invent their business models we are unlikely to see the real productivity benefits at a national level. For individual firms, those that recognise that technological and business model innovation need to go hand in hand are most likely to derive the benefits from the next production revolution.


Dr Chander Velu

Factories of the future



and implications for automation systems

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Where will we make things in the future and how will the concept of a factory evolve? How we answer these questions is changing, says Professor Duncan McFarlane, Head of the IfM's Distributed Information and Automation Laboratory (DIAL) and that is affecting our priorities for automation.

When we think of a factory we still tend to default to an image of a large building in which raw materials are transformed through a series of processes into finished products. That *idea* of a factory has not changed much since the first industrial revolution, even though our supply chains have become long and complex and production operations are spread over multiple sites. These days data is as much the lifeblood of factory operations as are the raw materials and manufacturers increasingly offer services as well as products. And, as we become ever more conscious of the impact manufacturing has on the environment and our natural resources, how we handle waste and re-use materials is a major preoccupation.

Our notion of the factory is, therefore, beginning to undergo a radical reconceptualisation. We see factories that no longer operate in isolation but are instead part of a complex production network in which different steps in the process take place in different locations. We have seen a growing trend towards 'late customisation', the manufacture of a core product which is then customised in a multitude of different ways. A good example of late customisation is the mobile phone, with one firm making the base processor and screens then sending them on to other factories where they are cased and packaged in a plethora of different ways.

Question: When is a factory not a factory?

Answer: When it's a shop, or a farm or a building site.

In other words, we are also seeing what could be described as conventional manufacturing activities taking place in non-factory settings. This could be anything from the machine in a DIY store that mixes and produces your paint while you wait to the harvesting and processing of lettuces destined for the supermarket shelves. Equally, the big construction companies are becoming much more factory-like both on site and in making modular components offsite.
So we increasingly have mobile, small-scale, one-off production that does not necessarily take place in a factory.

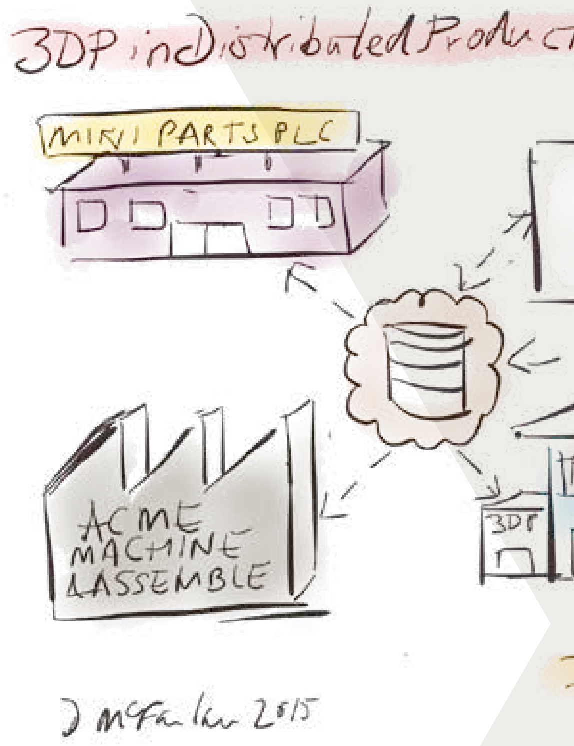
At the same time, we see the concept of a factory encroaching into 'non-making' environments such as airports, logistics, hospitals and repair stations. These types of organisations are increasingly adopting factory-like approaches and processes and share many of the operational challenges faced by factories, such as resource constraints, cost thresholds, quality targets and customer service levels.

Question: What does this mean for automation?

Answer: As the boundaries of manufacturing expand, we encounter a whole new set of challenges for automation.

In this context, it is important to define our terms by making a distinction between automation and computerisation (or digitalisation). The two things are not synonymous. Early instances of automation involved almost no computerisation – the automation of transportation with railways, for example, or agriculture with tractors. Equally, there are plenty of activities in which computerisation supports manual operations and has nothing to do with automation. But the key space – and the one we are interested in – is computer-based automated operations.

In our conventional manufacturing model, firms have tended to focus on three core imperatives: productivity, sustainability and resilience. From an automation perspective that has resulted in a number of outcomes such as automating asset



maintenance to increase productivity or integrating energy and emissions control with production operations to improve sustainability. Firms wanting to become more resilient seek fast detection of disruption and dynamic ways of managing their processes.

But how can automation continue to improve productivity, sustainability and resilience in these new manufacturing paradigms?

The trend towards specialisation, customisation, distribution and servitization demands a whole new set of requirements. Specialisation means firms need to be good at automating not just how they make things but how they set up the equipment to make things. To customise, firms need to excel at tracking products through the supply chain. For distributed manufacturing, firms need to develop efficient production management

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Integrating 3D printing with conventional production

One of the new production models is likely to be distributed manufacturing. This poses a number of challenges, not least the co-ordination of production with logistics. In a recent project, the DIAL team looked at ways in which cloud computing can be used to distribute and manage the operations of production sites from a single control system. In particular, it focused on 3D printing and how to integrate it with conventional manufacturing across multiple sites.

strategies, perhaps using the cloud to enable the coordination of multiple sites with one system. For firms looking to develop services, one of the key challenges is how can they couple information with physical products and systems in order to deliver not just a product but a service associated with that product.

Clearly, many of these automation strategies fall within the scope of initiatives that are loosely characterised by the term 'the Fourth Industrial Revolution'. Industrie 4.0, with its focus on the computerisation of manufacturing, and the development of the Industrial Internet of Things certainly encompasses some of these automation agendas. But while IR4 – and its associated terminology – can be helpful in supporting the drive to digital we have to guard against seeing it as an end in itself. Firms need to understand the drivers of innovation as well as their own strategic objectives and develop clear-minded automation strategies to support them.

Automating resilience at Boeing

Boeing's Interiors Responsibility Center (IRC) has to manage high levels of customisation. Each of Boeing's airline customers has its own branding and often uses different branding for different routes. At the same time, the specification of aircraft interiors is becoming more and more sophisticated as new technologies emerge and airlines become more attuned to the psychological and physiological effects of flying on their passengers.

The IRC factory runs on 'lean' manufacturing principles but finds that variability in the composite components can cause disruption to the production line. Boeing asked DIAL to do a number of things: to identify the type and scale of disturbances that were affecting production operations, propose better methods to assess the balance between lean and resilience and to improve track and trace concepts that can be adopted within production control systems.

The Cambridge team specified more intelligent production control systems and tighter raw materials and part tracking that will tolerate higher levels of product variability and which can also dynamically alter the balance between lean and resilient operations to cope with disruptions.

Professor Duncan McFarlane

Back to the drawing board

Design for additive manufacturing

Additive manufacturing (AM) technologies have resulted in significant changes to the way we design by enabling early prototyping of complex components. But the uptake of these new production methods beyond prototyping and small scale production remains slow. Part of the problem, contends Dr James Moultrie, Head of the IfM's Design Management Group, is that industrial designers don't have the know-how to make the most of these new technologies for series production of components.

AM has the potential to transform not just the way things are made but every aspect of how firms go about meeting their customers' needs, whether through customisation, supply chain reconfiguration or wholesale business model innovation. But if AM is to move beyond prototyping and small-scale production and become mainstream, industrial designers need to embrace its possibilities.

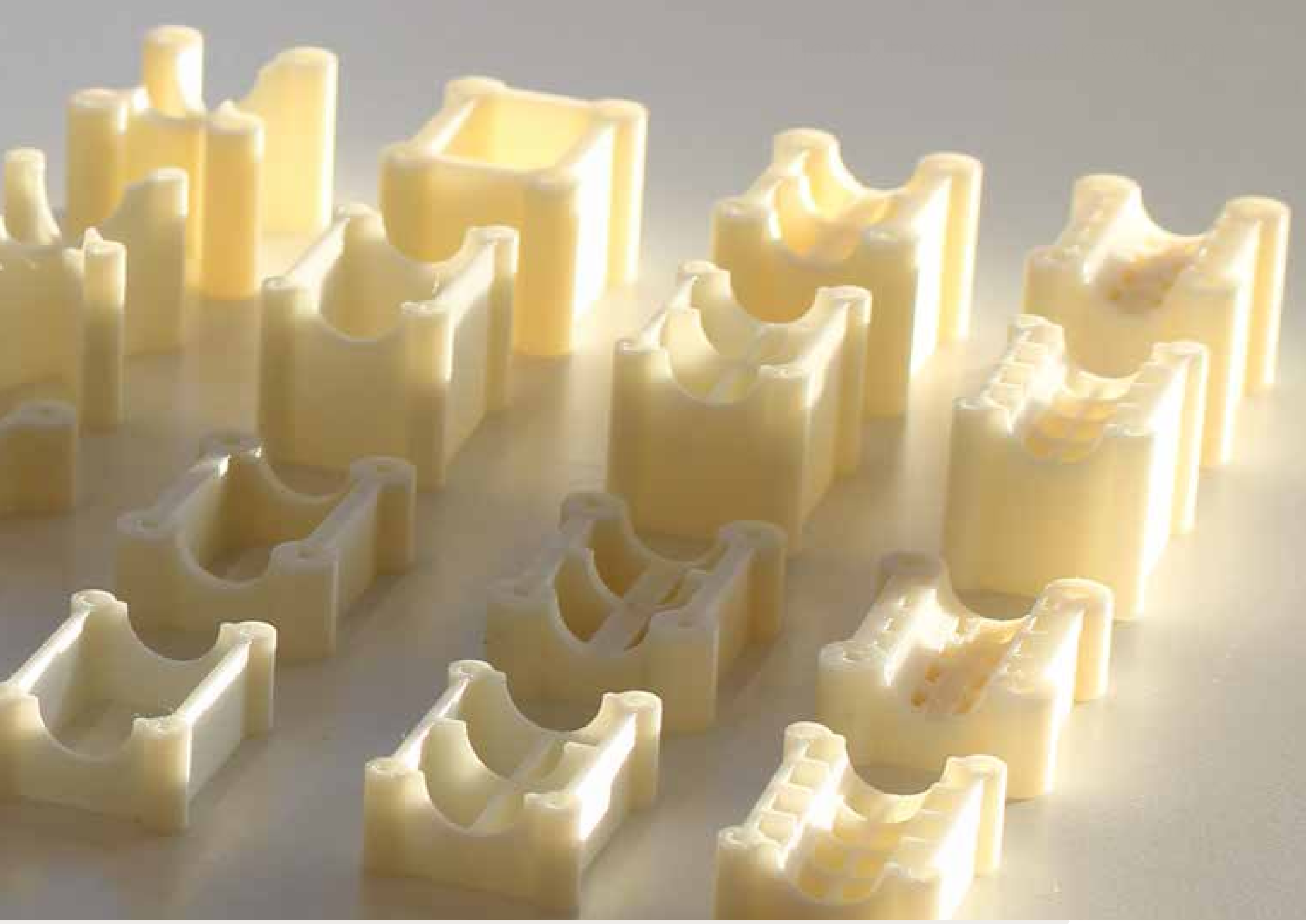
As part of a recent research project, we surveyed 110 product and industrial designers and design engineers from 25 countries. While 72% of respondents often or routinely use AM for prototyping and just under half said that they 'sometimes, often or routinely' use it for producing tools, more than 60% said they had never designed end-use components for production with AM.

Reasons for using AM

The survey respondents said that they would choose additive over conventional manufacturing processes when they were dealing with low volumes, complex shapes, shape manufacturability and customisation. The main reasons given for not choosing AM were perceptions around cost and speed, concerns over repeatability and dimensional precision and over the material properties of components. Designers also noted that there is a lack of information to support design decision making. The information that exists focuses on 'printability' but printability in itself does not guarantee parts which are cost-effective when produced in volume.

Whenever a designer designs a new component, they do so with an understanding of the limitations and requirements of the production process which they will be using. An injection-moulded part must have constant wall thickness, webs to support raised features and smooth transitions between surfaces. These 'rules' and principles are well established and are readily available in textbooks and online sources. The same is true for the majority of production processes.

But where do designers look for information on how to design parts to take advantage of AM for series production? The hype says that 'anything can be



More than 60% of industrial designers have **never** used additive manufacturing for series production.

produced' and that 'complexity is free'. Designers are suddenly freed from the shackles and constraints of conventional processes. But is this true? Does AM provide limitless possibilities, or are there rules which can be applied to help designers make effective design decisions?

To be able to exploit AM capabilities for series production, designers, engineers and manufacturers need to understand how its processes differ from other manufacturing processes and how they can be best deployed. This means, in effect, going back to the drawing board – totally rethinking the concept of design for products made using AM.

Some new design principles

We have been working with industrial partners to develop a set of design guidelines that will help accelerate the uptake of AM as an economically viable production process and also help designers understand how they can take advantage of the capabilities of AM technologies. As a result, we have begun to codify some design principles, which aim to help designers design components which take better advantage of AM for series production.

Dr James Moultrie

Design for additive manufacturing: some new rules

1. Use the least material possible
AM is often a slow process, and comparatively simple parts can take many hours to produce. The less material used, the less time taken. Thus, shape optimisation to eliminate excess material might be beneficial.

2. Don't print air
As the print head moves around the build volume, time and therefore cost can be minimised if the shape is flat, has a low z-height and the shape isn't an open or enclosed box.

3. Define and connect functional surfaces
Challenging conventional ways of thinking, it can be advantageous to first define the functional surfaces of a part and seek to join them in the most efficient way possible.

4. Minimise shape complexity
Despite the claims that anything can be printed with AM, complexity is expensive. The more changes of direction and greater distance the print head has to move, the longer a part typically takes to print.

5. Minimise infill
In certain AM processes, 'solid' shapes are not solid and comprise a surface which encases 'infill' (a honeycomb lattice) which holds the shape together. This infill is a form of 'support structure' and serves little functional purpose, whilst taking a long time to print. Thus, reducing or eliminating the need for infill can make parts more cost effective. This often results in parts which are more 'shell' like.

6. Minimise support material
Support material is generally indicative of a part which has not been optimised for AM production.

7. Enable nesting in the build volume
Parts which 'nest' together enable multiple parts to be built at the same time.

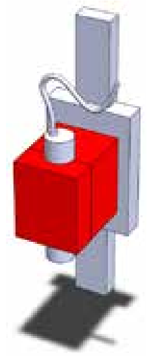
8. Enable tessellation of parts in the build volume
Tessellation also enables multiple parts to be built at the same time.

Rules for design for manufacture for conventional processes are well established. AM requires new ways of thinking, especially if designers are to progress from designing parts which are 'printable' towards parts which genuinely take advantage of AM as a production process. This is at an early stage, and may explain why take-up of AM as a series production process among the industrial design community has been limited to date.

It is our hope that AM might begin to be more routinely considered as a manufacturing choice for series production by industrial and product designers.

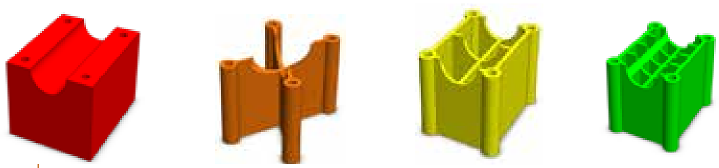
This research project has been carried out in collaboration with Loughborough University and was funded by the EPSRC.
Read more at
www.d4am.eng.cam.ac.uk
Or contact Dr James Moultrie:
Email: jm329@cam.ac.uk

Putting the rules into practice

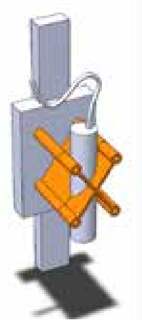


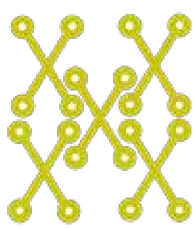
The graphic (right) is of a simple device for holding a sensor on a machine. The two red components are designed as you might imagine they could be for machining. They are 'printable', but they do not take good advantage of AM as a production process.

We tried a range of alternative designs (below and the photograph on page 22), to see how they influenced the build time and cost. The results showed that the most effective solution can save a significant amount of time and therefore cost, in a single build.



More significantly, this shape tessellates, enabling multiple parts to be produced in a single setting.





Intelligence services

With new technologies appearing more rapidly than ever before, how do you pick the ones that will deliver competitive advantage and spot the ones that could threaten your business?

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Dr Letizia Mortara, Senior Research Associate in the IfM's Centre for Technology Management, says companies need comprehensive technology intelligence (TI) systems to make sure they spot relevant new technologies and understand how effective they are at doing so.

Artificial intelligence, augmented and virtual reality, nanotechnologies, synthetic biology, 3D printing, driverless cars and interplanetary travel: new potentially disruptive technologies and speculation about how they will evolve appear in the media on an almost daily basis. But how do you know which of the emerging technologies will present an opportunity or threat to you and your company?

Picking up the early warning signs and understanding the implications of new technological trends is not a trivial or straightforward task. Just 'Googling it', for example, will not deliver sufficient insights for the identification of new technology opportunities and support the implementation of an effective strategy for businesses in today's competitive market.

TI activities aim to identify early technology breakthroughs and trends that could create long-term competitive advantage or could impact negatively on the business. As firms come under increasing pressure to maintain a rapid pace of innovation they are dedicating more resources to developing TI systems that can efficiently capture information from the external environment in order to develop insights that support a variety of decision-making and strategic planning activities.

TI activities span a firm's functions and roles and are often informal or carried out *ad hoc*. These may include scouting networks, patent mining tools, calls for information via idea competitions or working with external intermediaries or consultants that search and communicate the new trends for you. Although most firms carry out some form of TI, relying on *ad hoc* approaches makes it hard to evaluate if a TI system is making an effective contribution to the company's performance.

Furthermore, even if there is extensive and specific knowledge within a company about approaching technologies, getting that information efficiently and accurately to decision-makers can sometimes be difficult. So how does a company know if the technology intelligence system it has put in place is performing well?

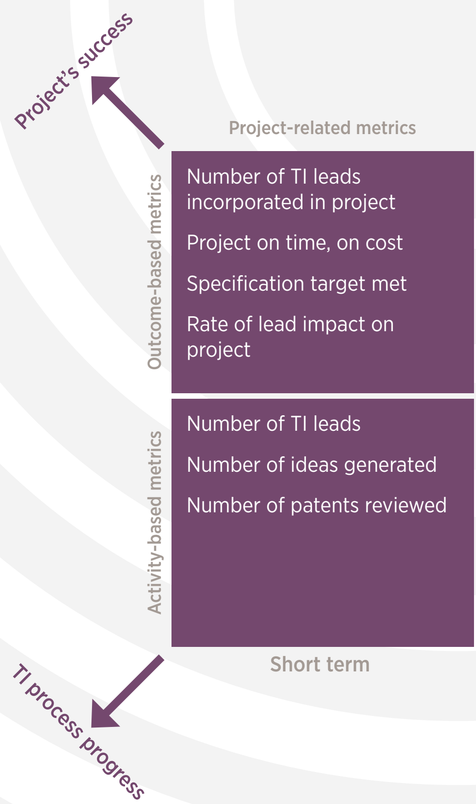
Evaluating the quality of technology intelligence: effective and efficient TI

We wanted to develop a framework that companies could use to evaluate their TI system regardless of what type of TI activities they are undertaking. To this end, we reviewed what companies are doing in practice and integrated our findings with an academic understanding of the development of impact measurements. 12 global companies ranging in size from 800 to more than 250,000 employees participated in this research. We asked the companies how they undertook and measured TI – both formally and informally.

We used their responses to develop the TI evaluation matrix (see right) which incorporates the main strategies being used by companies to measure TI performance and suggests that companies should use a combination of these metrics to appraise TI activities. This evaluation matrix can help companies do a number of things: contextualise their TI performance analysis; structure and organise their TI measuring and evaluation strategy; understand the limitations of some metrics and encourage them to adopt more than one method for measuring TI performance. The evaluation matrix combines measures of the intensity of the TI activity (how much TI work has been done) with the TI impact (the quality of the outcome of TI). These can be reviewed in the short-term (the success of a project) or in the long-term (the health of a company).

The evaluation matrix encompasses four types of metrics:

- **Activity-based and project-specific:** These are the most easily quantifiable metrics and are less subject to personal bias. An example of this metric is



TI evaluation matrix (Y.W. Loh and L. Mortara) with some examples of metrics in each category.

"...you do get people in management who think that everything is on the internet, where you can just Google [it]. We are trying to prove that in fact, this is not the case."

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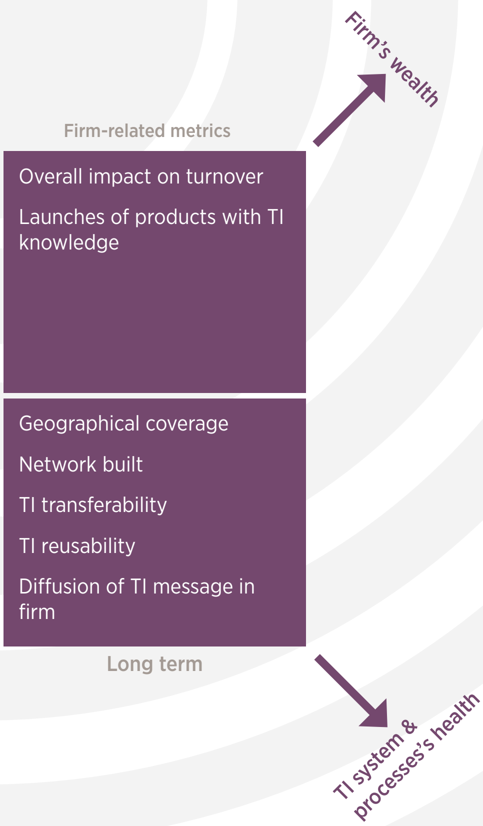
a measure of how much work has been done to review the trends and implications of new technologies for a project. For example, how many patents have we reviewed? These metrics are useful for understanding how far we have got in the review of the information available, but stays away from measuring what the information is telling us. This type of metric is useful when we want to avoid forming an opinion too early, based on only partial data and hence it is useful for TI reviews which take a long time. However, as the extent of the TI effort is not necessarily reflected in the final outcome, other metrics are needed to complement these.



- **Activity-based and firm-specific:** This type of metric evaluates how TI is benefiting the whole company. It looks, for example, at how established and integrated the TI activity is with the rest of the organisation. For example, are we capable of using TI insight to guide the firm? Can we do patent analysis? Are we aware of what the cumulative TI insights are telling us? Can we embed these in our decisions and planning systematically?

- **Outcome-based and project-specific:** Some metrics are employed after a project is completed and evaluate the success of the project for which TI was gathered. However, as a project's success can be impacted by many other factors beyond the quality of TI, such as the resistance of a decision-maker to act on the insight, this measure cannot be used in isolation.

- **Outcome-based and firm-specific:** This is important for measuring the long-term effectiveness of TI for the company. Data needs to be collected over a long time period to understand whether TI activities are suitable for the company needs and are helping it survive and prosper. Very few of the companies surveyed measured TI in this quadrant and it is often subjectively measured as a 'sense' or 'feel' about how well TI is delivering value to the firm. However, if short-term metrics are not used in combination with these long-term ones, the TI officers might struggle to demonstrate the value of their work.

Communicating technology intelligence

This evaluation matrix is useful both as a structured way of capturing and assessing the range of TI activities within an organisation and as a way of communicating the importance of TI to decision-makers.

This can be something of a challenge. All the companies we interviewed reported difficulties in communicating their TI insights to senior decision-makers. Even when the insights are clear, relevant and well-presented, they are not always acted upon. Much depends on the inevitably subjective perceptions and personalities of the decision-makers who sometimes tend to underestimate the depth and complexity of the TI activity. One of our interviewees said:

"...you do get people in management who think that everything is on the internet, where you can just Google [it]. We are trying to prove that in fact this is not the case."

If TI is to be a successful endeavour it needs to be well structured and well communicated. The evaluation matrix can help with the former and our practical guide, *Communicating Technology Intelligence*, can help with the latter. It can be downloaded at: bit.ly/2ygwD5t

Related short courses

If you are interested in TI and how it can help your organisation, join us for:
Technology and Innovation Management: 20–22 March 2018
Find out more at: bit.ly/2Amcc55

Technology Intelligence: date to be confirmed. Register your interest in attending at: bit.ly/2ysEjhv

Rethinking supply chains: the new globalisation

Dr Jag Srai. For more information, contact: jss46@cam.ac.uk

With the advent of new technologies, a changing geopolitical context and ever more pressing concerns about sustainability, are we seeing the emergence of a new form of globalisation? At the IfM's annual Cambridge International Manufacturing Symposium in September, leading industrialists, academics and policy makers came together to discuss emerging trends in global manufacturing, and whether the low-cost focus of previous decades is no longer the dominant design factor for twenty-first century manufacturing supply chains.

The explosion of information and communications technology from the late twentieth century has given us the means to connect across the planet as never before.

Losing its shine?

But globalisation, arguably, has become something of a tarnished brand. Developing nations, while providing the low-cost labour that underpins the global economy, face seemingly insurmountable barriers to growing their own export-led economies.

Developed countries are also experiencing political volatility as sections of their populations feel increasingly excluded from the highly visible wealth-creating activities of a perceived global elite. We are seeing a political backlash in countries such as the US and the UK, with leaders looking to protect their industries and control their labour markets.

There are other factors at play. Sustainability, although not wholeheartedly endorsed by all governments, is clearly an imperative for many, and for the majority of multinationals that need to respond to the concerns of their customers, staff and stakeholders. And the big players in global manufacturing are taking their commitment to sustainability very seriously. At the Symposium we heard, for example, about Procter & Gamble's ambition to ensure all its manufacturing sites are carbon neutral by 2020 and DHL's Life Sciences and Healthcare Division's commitment to be carbon neutral by 2050.

Squaring the circle

But sustainability represents something of a paradox: customers around the world demand access to a 'global inventory', refreshed on a daily basis with new products that can be delivered to their door hours later. At the same time, they want large companies to reduce their environmental impact.

New technologies have the potential to square this circle. New production technologies mean we can envisage different ways of organising the movement of goods around the world. Distributed manufacturing can enable the production of goods close to the customer, in small factories with smaller supply chains delivering more personalised products and services at a lower cost to the environment.

Digitalisation can also support the 'circular economy', from smart design, fostering collaboration through to data sharing across supply chains, monitoring usage to prolong life and managing re-use. However, the scale of change needed to shift the manufacturing paradigm from large-scale global operations to more

This is an abridged version of an article by Dr Jag Srai, Head of the IfM's Centre for International Manufacturing (CIM), first published in The Manufacturer, *November 2017.*

Rethinking supply chains

Find out more about how we are supporting supply chain transformation:

- **The future of healthcare**: REMEDIES project. Read more at bit.ly/2B7Do8j
- **Food security**: TIGR^{2}ESS project. Read more at bit.ly/2niNoZJ
- Participating in the **World Economic Forum**'s Shaping the Future of Production Global Future Council (www.weforum)
- Contributing to the **OECD**'s Digital Economy programme (www.oecd.org/sti)
- **The digitalisation of supply chains.** Read our executive briefing at: bit.ly/2ksnpem
- The 2017 Symposium at

local-to-market, distributed manufacturing is enormous. But there are perhaps grounds for optimism as large global companies - driven in many cases by the triple bottom line of social, environmental (or ecological) and financial - are trying to embrace the opportunities the Fourth Industrial Revolution presents.

Innovation - the way ahead

Our speakers at the Symposium reflected many of these challenges: an understanding that they must innovate or die. They all have programmes of digital innovation and experimentation underway. In this world of fast-moving technological and social and political change, trying new approaches, seeing what works, capitalising on success and moving on fast from failure is the only way forward.

But many of the global behemoths - while they can see change heading towards them at speed - may not have the organisational capability to manage the disruption it will bring. Being able to embrace innovation will be key - but it is not easy. Even those large companies that think they are good at working with innovative start-ups present an impenetrable carapace to would-be collaborators.

Skills

A lack of skills is also part of the challenge facing organisations, particularly but not exclusively in the boardroom. World Economic Forum analysis suggests that companies and governments need to think about completely different models of employment that allow people to reskill throughout their careers.

The skills gap is widely acknowledged to be a barrier to digitalisation, but the solutions tend to focus on educating new entrants. While educating the next generation is clearly vital, so is developing a lifelong learning approach for staff at every stage of their careers.

The effect of technology

Beyond the skills challenge, another key theme is the role of technology in future supply chains. To what extent will new technologies drive efficiency gains as part of a technology push dynamic, focusing on cost improvement and productivity? Or will future supply chain business models drive new ways of meeting consumer needs, with the supply network design agenda shaping technology development programmes?

The challenge here is that these new supply solutions are not going to be easily arrived at in the traditional functional silos within which large organisations operate. They will more likely involve multi-functional technology and business-savvy teams spanning organisations.

Whichever of these dynamics play out, the days of the large monolithic factory operation, churning out standardised products at global scale, located far from the point of consumption seem increasingly at odds with the recent trends for more customised goods, shorter lead times and greater scrutiny on the provenance of the product.

Indeed, the triple bottom line analysts' approach will demand that social and environmental as well as financial criteria are met. Sound labour and environmental practices and resource efficiency in product manufacture and supply will drive change. Increased visibility and transparency will mean that the ethics of alternative supply arrangements can form part of the new assessment criteria for sourcing and supply decisions.

These challenges – while not altogether new – will shape developments in the footprint of future manufacturing supply chains and will require the attention of industry, governments and academia as we all try to accelerate the shift to a new kind of manufacturing – one that will deliver economic and social value while safeguarding the world in which we live.

Read more about the 2017 Symposium at: bit.ly/2kTfxCa

Take part in the conversation

Advanced technologies will continue to have a major impact on supply chains. We will be returning to this topic at our next Symposium when we will consider supply chain transformation enabled by advanced technologies: implications for producers, consumers and society.

It will take place on 27 and 28 September 2018. If you would like to join us, register your interest at bit.ly/2o4UpO7

Equipping engineers for the next production revolution

The rapid technological changes driving the next production revolution are challenging the adequacy of current engineering education and training systems (OECD 2017). Tom Ridgman explores the history of engineering education and how we should be educating the engineers of the future.

While there is no argument over whether higher education institutions (HEIs) should be developing graduate-level work skills, there is much disagreement on what this looks like and what work skills are actually needed by a graduate engineer in the future.

The natural first step is to understand what employers need. But this is no simple task. The majority of graduate engineers will not end up working in the same discipline domain that their degree is in. A number of game-changing technologies are now maturing, which is creating a rapidly changing industrial workplace with new production processes and digital technologies. This not only means changes to the machines operating in a factory, but also changes in the role of engineers in a factory.

History of engineering training

Currently, half of the nationally accredited engineers working in industry have a degree in engineering – the other half don't. This split between engineers with and without university degrees is historical. Engineering as a discipline in the UK only really began during the religious wars of the 1500s. Armies got so big that they could no longer live off the land and needed to build roads, buildings, storage facilities and supply chains to provide the resources that they needed. For the next 250 years engineering was a practice-based discipline with engineers learning through workplace application.

It was only in the 1800s that the idea that engineering could be a taught subject began to get traction. By the 1890s this concept had expanded and there were a number of institutions teaching engineering across the world.

Critiques of engineering education

There have been numerous formal assessments of engineering education since engineering first moved into the classroom and an increasing need to assess whether a graduate engineer is competent. The Mann Report identified the following key issues:

- The majority of four-year courses are taught as two years science and two years application – theory and practice should be taught simultaneously.
- Examinations as an assessment method are unconnected with teaching.
- Fields of application are expanding and teaching is not keeping up.
- Engineering courses have high drop-out rates.
- There is a poor correlation between exam grades and the quality of graduate work.

You might be surprised (or not) to learn that the Mann Report on US Engineering Education was written in 1918. It contains many of the same critiques that are commonly identified in contemporary reviews of university engineering curricula.

In addition to these challenges, there is also a series of preconceptions about engineering that may be preventing students from choosing it as a career. Engineering is seen as a problem-solving discipline. It is assumed that learning is hierarchical and that its students require skills of analysis and modelling in abstract maths and physics to be successful. This can put off potential students who have more creative preferences.

Another challenge is that many engineering graduates do not end up working in the engineering discipline that they specialised in. For example, only about 40% of mechanical engineers go into mechanical engineering, while the percentage for specialised engineering disciplines can be as low as 15%. This means that there is a risk that the depth and breadth of knowledge and skills is inadequate for the graduate's first post. HEIs are recognising this and evolving their engineering programmes to give students skills that are transferable to different workplaces, such as data analysis and problem-solving skills.

Project, problem solving and workplace placement learning

There has been increasing interest over the past decade in alternative education methods that are designed to give engineering graduates experience in solving real-world problems and to demonstrate the transferability of their knowledge. Examples of this include problem/project-based learning, hands-on learning and capstone subjects. All of these methods aim to bring together the knowledge and skills learned by a student during their degree and then to apply this in a project or workplace. These different approaches have had varying degrees of success, with those that are most successful being integrated with innovative teaching and learning methods throughout the degree.

The University of Cambridge's Department of Engineering undergraduate degree gives students a broad scientific and engineering background and an in-depth knowledge in areas that students choose to specialise in. There is also a strong focus on developing important transferrable skills, which incorporates the ability to apply problem-solving strategies, a creative approach, team-working skills, ability to analyse data, written and oral communication and presentation skills, and research skills.

The Manufacturing Engineering Tripos (MET), which is an option for the final two years of the Cambridge four-year undergraduate degree, provides students with a grounding in management and manufacturing technologies. Key components of these two years include completing a major design project to develop a new product with real business potential, in tandem with understanding the market, producing a comprehensive business plan and assessing the product's financial viability. In addition, students work together in groups to undertake a series of structured industrial projects to solve substantial issues within a company.

The Advanced Course in Design, Manufacture and Management (ACDMM), originally a Postgraduate Certificate Course and now run through the IfM as the MPhil in Industrial Systems, Manufacture and Management (ISMM), was set up to bridge the gap between the capabilities of new engineering graduates and the requirements of industry. It achieves this by intensive tuition, with each graduate completing up to nine in-company projects and visiting up to 100 companies.

The course uses a mentoring approach that looks at both subject and skill competence and encourages the graduates to think for themselves how they need to develop in order to position themselves for the career of their choice. The intention of this is to try and build a framework that will allow graduates to manage their own learning, not only during the course, but also throughout their professional career.

Where do we need to go in the future?

While HEIs are making changes to how they teach engineering, there is still a mismatch between the discipline/knowledge-based nature of academic departments and the predominantly skills-based requirements of industry. Practical industry-based projects like those mentioned are helping to increase the industrial exposure of many graduates and give them the skills to adapt their life-long learning skills to different workplaces.

However, we can still do more. Future engineering education needs to expand further out of the classroom to better replicate the complex and changing environment that is experienced once a graduate enters the workforce. This means that engineering education needs to move further away from its focus on assessment tasks with definite answers, to reflect the great complexity of the discipline of engineering – and not just technical complexity. To support the intellectual development of our students we need to help them to understand how to use ambiguous knowledge in complex problem solving. This includes learning how to find knowledge, evaluate it for its usefulness for the problem in hand, recognise and overcome the barriers to use and test it where necessary.

We need to continue to extend the technical focus of engineering education to incorporate business and social knowledge and skills. We also need to shift from just understanding elements to understanding systems and their relationships.

In a world where knowledge is available at the press of a key, the competitive advantage lies in understanding when, where and whether to use it. The engineers of the future will be most valued for their knowledge and skills in relating rather than applying, representing rather than transferring and their ability to rationalise and experiment. Having strong capabilities in these areas will enable engineers not only adapt to new technologies and production processes, but to develop and lead them.

Tom Ridgman has spent his career working to develop and improve national and international education and measurement standards in engineering, serving as Chair of the Registration and Standards Committee for five years, which oversees University accreditation and registration for Chartered and Incorporated Engineers and Engineering Technicians. He is also on the Board of Trustees of the Engineering Council, chairs the Quality Assurance Committee and is an ex-officio member of the Registration and Standards Committee and the International Advisory Panel.

Tom Ridgman
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PhD Spotlight

Katjana Lange: nano-scale superconductors

Research area:
Industrial photonics and superconductivity
Centre: Centre for Industrial Photonics
Degrees: BEng in Precision Engineering (University of Applied Sciences and Arts, Göttingen)
Supervisors: Professor Bill O'Neill and Dr Martin Sparkes

PhD Title: Ultrafast Machining of High Temperature Superconductor Nanostructures for Novel Mesoscale Physics

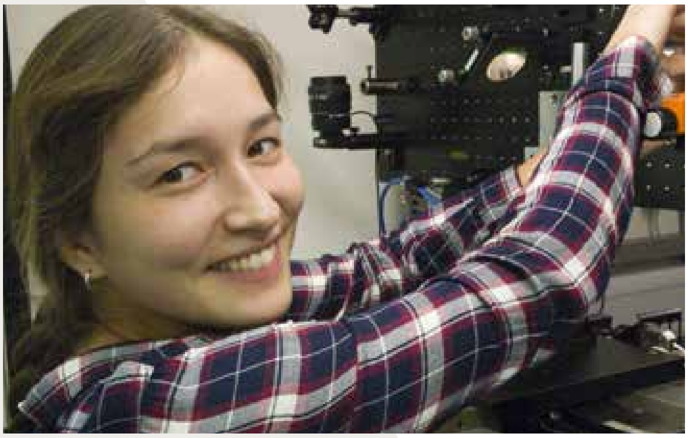
What are you hoping to discover/solve through your research?
My aim is to machine high-temperature Yttrium Barium Copper Oxide (YBCO) superconductors without degrading their electrical properties. Superconducting materials are generally very sensitive and can easily lose their superconducting properties due to heat, chemicals, humidity, ions, electrons, etc. By using an ultrafast laser, I hope to be able to directly vaporise material without any heat effects.

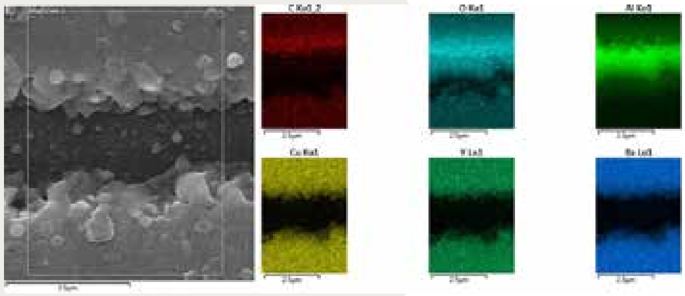
I want to avoid all sources of possible degradation and create nano- and micro-patterned YBCO thin films that can then be used in various small-scale applications. The best-known small-scale application of this technology is in superconducting quantum interference devices, also known as SQUID magnetometers. These SQUID magnetometers are sensitive enough to measure magnetic fields generated by the heart and brain and are used in hospitals for cardiology and neural magnet field imaging.

So far, what has been your biggest challenge during your PhD?
One of the main challenges at the beginning of my PhD was to build up a support network of people in the superconductivity field that I could seek advice from. I did not know a lot about superconductivity and had to ask different research groups about all kinds of things, from physics to maintenance and measurement procedures. Another challenge has been the laser machining itself and understanding the laser-matter interactions. YBCO is quite a unique type of material and the laser parameters need to be chosen carefully in order not to damage it.

What has been your biggest win?
My biggest win so far was to design my sample structure, machine it, and analyse it for incremental optimisation. I have also developed a network of people who support and provide me with knowledge and measurement technologies inside and outside the Centre for Industrial Photonics.

Have there been any surprises along the way that have influenced the direction of your research?
Although I knew about the complexity of laser processing, it still surprises me just how





much the different parameters can influence the material's behaviour. You often expect a certain result and get something completely different.

What was it that made you interested in studying precision engineering?
I have always been interested in machines and the way that the parts work together to make something new. What fascinated me about precision engineering was that all parts have to work together on an incredibly small scale. Suddenly, you need to consider the air movement in the lab or some other small 'invisible' influence, which can seem ridiculous for common 'rough' engineering applications.

What would you like to do after you complete your thesis?
After completing my thesis, I would like to work in the superconductivity or watch industry.

What do you like to do outside of your research?
Outside of my research I am basically investing all of my free time into ballroom and Latin dancing. Most of the weekends during the dance season I am travelling throughout UK to compete. For those competitions I train up to five days a week.

Making things better

Andrew Hawes
Advanced Course in Design, Manufacturing and Management (ACDMM) (1996)
Job Title: Director
Organisation: Newton
Location: Oxford

Why did you decide to study ACDMM?

Originally, it was the design element that attracted me to the course. However, the course changed the direction of my life forever. I found the impact that was possible in the manufacturing environment exciting. I enjoyed the practical and real environment of the shop floor. It was far less glamorous than design, but it appealed to me.

Tell us about how you came to establish Newton?

The story of Newton started in 1997 when Tom Wedgwood, Kevin Jones (also Cambridge graduates) and I joined another relatively small consultancy within a few weeks of one another. Looking back, this was an incredibly formative experience where our professional respect for each other and friendship grew strong. We learned a lot from the incredible highs and lows and good and bad of this company. The result was that when I started Newton in 2001, age 26, we knew what we wanted to achieve and what we wanted to avoid.

We wanted to put people first, both in terms of our clients and the people that would work at Newton. We wanted high levels of respect for our clients and their achievements and to see them as part of the team, integral to our success and never to be taken for granted. We wanted to guarantee all our work so that if we didn't add value, we wouldn't be paid. We wanted professional integrity, a team full of exceptional calibre people with drive and energy. A company where being nice to one another is valued and normal. Where friendships are commonplace, fun is integral and personal lives are seen as important. We wanted supporting colleagues to trump scoring points. We knew that success requires a team loyal to one another and in it for the long term. We understood the importance of a shared vision and the buzz of a common goal. We are driven by a belief that everything can be better.

The three of us grew closer and following the employees of our old firm attempting a management buyout that didn't happen, the three of us made a plan together to set up Newton. We had what we thought were ambitious plans to grow to 30 people and we simply didn't have the imagination to picture what it looks like today with a team of 250.

What were your goals when setting up Newton and have those goals changed as the company developed?

Some things haven't changed; fun, friendship, high performance, guaranteeing the value we add to clients and growing the firm so that we can do bigger and better things are as important now as they were in the early days. However, lots of things that were right back then aren't relevant now. For example, when we set up we were called Newton Industrial Consultants and yet now we do fantastic work in health, social care, finance and business services, hence we are now just Newton. We didn't have a physical office until 2007 but life would be much worse now without the 45 great people we have in our office supporting our client facing team.

One question I have been asked a lot over the years

"We wanted supporting colleagues to trump scoring points. We knew that success requires a team loyal to one another and in it for the long term. We understood the importance of a shared vision and the buzz of a common goal. We are driven by a belief that everything can be better."

"ACDMM was an incredible year; the practicality of the learning and the direct, rapid application of theory into real results was a wonderful way to understand and see business and operations in a new way."

Andrew Hawes

is how will we maintain the culture in the future as we grow (we've grown at an average of 25% per annum since 2001 to over 250 people). I don't think that is the right question as we need to ask ourselves what we want to hold on to and what we should change to be better. We've been lucky enough as a firm to appear at or near the top of polls as an employer – *Times 100*, *Glassdoor*, *Financial Times* – and we are proud of our culture and the way it has evolved, and will continue to evolve, for the better.

What type of projects does Newton work on?

We have major programmes with retailers, hospitals, food manufacturers, defence programmes and with social care providers. A really broad set of clients; what unites them is their level of complexity. We believe that the bigger the challenge the better. In fact, there are many projects we work on that other organisations would consider too tough. We work with our clients to help them provide better service and save tens of millions of pounds.

What is the most rewarding experience you have had at Newton so far?

I love the scale of what we can do now – three programmes last year each saved clients over £100m per annum while improving the experience of customers/service users and employees. However, the most rewarding stories I hear from our team are how the work we do helps save and improve lives of vulnerable people in the UK's health and social care system. They have on more than one occasion brought a tear to my eye.

What does an average day look like for you?

Although a cliché, I haven't had more than two days in the same place doing the same thing for 10 years. I meet clients before, during and after programmes, train and socialise with our team, and spend time on HR, marketing, leading and planning across Newton. I use my time travelling between sites to do a lot of my thinking and often spend that time on the phone with people across Newton working on current challenges and new ideas.

Are there any experiences from your time studying at Cambridge that have had a lasting impact?

The three years in my life where I believe I have learned the most are my year on ACDMM, my first year in work and my first year of Newton. ACDMM was an incredible year; the practicality of the learning and the direct, rapid application of theory into real results was a wonderful way to understand and see business and operations in a new way.

I made lifelong friends while studying on the course. I was recently on holiday with my family and three other ACDMM alumni families. In fact, we hired a mini-bus not dissimilar to the ACDMM vans. We did laugh as we had the three adults in the front, just like 20 years ago, but in the back were six of our kids rather than our classmates.

I had an interview for my dream job while on the course and I was worried I wouldn't interview well. One of the lecturers drove from Cambridge to Warrington to spend a few hours helping me. The generosity was not lost on me then and it isn't now. I remember I was worried that I was too unprofessional (in particular always late) and he said that this was just a habit and that I could decide to change this habit if I wanted to.

The main thing that I learned, is that everything and certainly every business can

“The main thing that I learned, is that everything and certainly every business can be improved and made better. We met lots of good people at (mostly) good companies, but the complexity and dynamic nature of businesses means that there is opportunity everywhere.”

Mountaineering in the Himalayas after graduating, from left, Andrew Hawes, Jim Purves and Greg Thomas

be improved and made better. We met lots of good people at (mostly) good companies, but the complexity and dynamic nature of businesses means that there is opportunity everywhere. A lot of the basic concepts we learned at the time such as lean and work studies have stayed with me. At the heart of Newton’s methodology is the theory of constraints (*The Goal*, by Goldratt) which I studied at Cambridge. Much harder to implement than lean, but much better.

Looking back, I also had two horrendous suits. One was green and the other was Miami Vice white. I have no idea what I was thinking; perhaps we needed a lecture on image.

What is the most useful advice you could offer to a current ISMM student?

Graduating from the course offers a world of opportunities. Accept that while you could do almost anything, you actually have to do something, so you can’t do everything. I know this sounds obvious, but I have interviewed literally hundreds, possibly more than 1,000 graduates and have the pleasure of working with 250 fantastic people, the majority of whom graduated from Oxbridge and there seems to me to be a common trait to success.

Obviously think carefully and choose a job that excites you, but those that put 100% into the situations they are in seem to achieve the most. The most frustrating people are those that spend their time in a limbo, always wondering if there are better options elsewhere. Ironically, the people who get furthest seem to spend the least time planning their careers, but they do achieve great things wherever they happen to be and they make the most of now. So be curious, ask questions, do lots and throw everything into what you are doing today, in and out of work. From what I see, those that do that end up with a lot more options, have more fun and achieve the most.

What is your biggest passion outside of work?

While at Cambridge we had a visiting lecture from an ‘entrepreneur’. He asked us to put our hands up if we wanted to be an entrepreneur and lots of hands went up. He said we should keep our hands up if we were prepared to work all the hours we had to achieve our goal. Some hands went down. He then asked if would we prepared to not see our kids, lose friends, get divorced and put our entire financial future on the line to make it work. He said anyone with their hands still up might make it. I couldn’t disagree more. In my opinion what I heard didn’t represent success at all. I’ve worked incredibly hard at times and for sustained periods, but I have always enjoyed lots of skiing, surfing, endurance sports and proper time with my family and friends.

Dr Rob Phaal, from the IfM's Centre for Technology Management, is a world-leading expert on strategic and technology roadmapping.

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