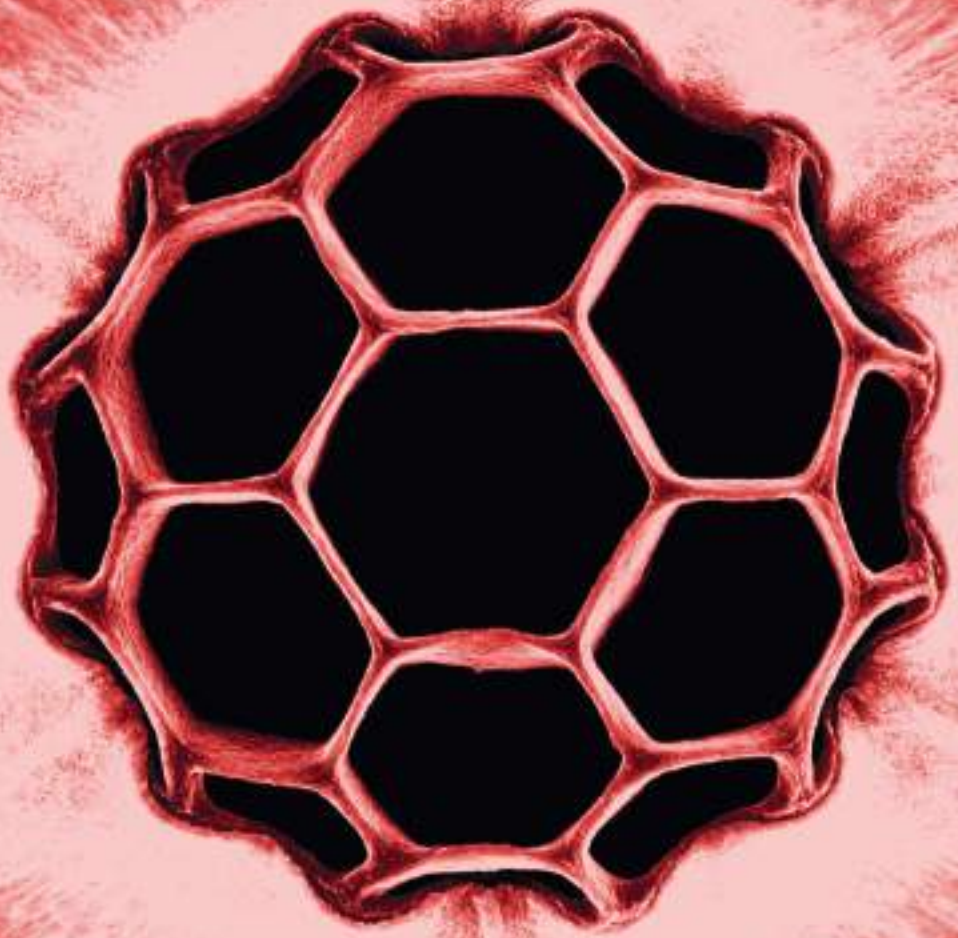
SPRING/SUMMER 2019 | Issue 10

Institute for Manufacturing REVIEW



Capturing value...

- Understanding the real value of manufacturing
- Resource efficiency for sustainability and better business
- Rediscovering value through circular economy
- Scaling-up technology innovations for customised products
- Harnessing intellectual property value in start-ups

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: Nanotube bouquet' image by Sarah Jessl, taken while she was a PhD student in Michael DeVolder's Nanomanufacturing group at the IfM. Sarah's image won the Annual Photography Competition at the Department of Engineering in 2018.

'Nanotube bouquet' was captured using a scanning electron microscope. A casual glance suggests the carbon nanotubes are in a ball; but actually they are in a bunch, forming a hexagonal honeycomb, which when viewed from the top appears as a symmetrical bud. The Carbon nanotubes are seamless rolled-up graphene sheets which have extraordinary mechanical and electrical properties. Organising these nanotubes into specific structures allows researchers to tweak their properties to certain applications such as energy storage and sensors.

Contents

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IfM Review is published twice a year. Sign up to receive a copy by email and to hear about other IfM news at:
www.ifm.eng.cam.ac.uk/research/ifm-review

Welcome to Issue 10

A warm welcome to the *IfM Review*. It seems apt that we are publishing our tenth issue in a year when we celebrate ten years since we moved into the Alan Reece Building on the West Site. This year also marks 40 years of the Manufacturing Engineering Tripos (MET), the undergraduate track focusing on manufacturing in the last two years of the Engineering degree.

Issue 10 features articles with insights into a range of recent IfM work, around the theme of 'capturing value'. These encompass business, economic, social, consumer and environmental aspects of 'value' as a broad concept.

Our first two articles focus on policy. Dr Jostein Hauge and Dr Eoin O'Sullivan discuss their new report, 'Inside the Black Box of Manufacturing', which recently gained national media attention by showing that UK manufacturing is being undervalued in economic value in the official statistics used by policymakers, with significant implications for industrial strategy. The second article, by Dr Carlos López-Gómez, Head of the IfM's Policy Links Unit, explains a recent study into evidence from a number of countries on the real impact of governmental investment in digital manufacturing – the report provided key evidence for a £120 million funding boost announced by the UK government.

We then turn to look at 'value' in terms of resources and sustainability, and how these can support business and economic development. In an article on resource efficiency, with some stark statistics and eye-opening examples, Professor Steve Evans explains why industrial sustainability and profit go hand-in-hand. Better use of resources certainly captures value: it makes good strategic business sense as well as being better for the environment, and is often more straightforward to achieve than might be assumed. Dr Curie Park's work in Thailand explores how grass-roots projects can develop circular economy concepts, taking waste materials and using them to stimulate innovation projects in local communities. Her pictures of beaches in Thailand do not fit the tourist ideals, but her work provides inspiration and test-cases for changing habits for better outcomes.

Our interview with Dr Jag Srai also explores sustainability issues, this time within the context of e-commerce in the food supply chain. There is clear value for consumers in the convenience and delivery speed provided by online grocery shopping, and a valuable new market opportunity for companies in the sector, but is this unchecked consumerism environmentally sustainable? Jag shares his thoughts on the challenges of the 'last mile' of delivery in developed countries, the resource scarcity problems of the current global food system for developing regions, and whether digital platforms can offer solutions to help address these issues and capture value for industry and consumers.

Dr Ronan Daly and Dr Cristina Rodriguez-Rivero consider how value can be unlocked in manufacturing through scalable customisation – developing technologies to deliver higher-volume, lower-cost customised products. Customers are increasingly seeking personalisation, so there is an opportunity for manufacturers who can provide personalised products in higher numbers without breaking the bank. Current IfM work with Pilkington provides fascinating insights into how this can be achieved, with late-stage customised inkjet printing of electronics onto large curved glass surfaces.

An article with IfM Industrial Associate Rob Munro explains a recent project helping to transform innovation in the rail sector, focusing on improving customer experience. We also hear from Dr Frank Tietze on how start-ups and growing companies can capture value through their intellectual property, ensuring that their IP strategies align with business objectives.

We hope you enjoy these articles, along with a variety of recent IfM news pieces, and a brilliant example of student innovation in our 'Student Insights' piece on the CU Spaceflight society's recent forays towards the stratosphere.

As always, we welcome you to keep in touch and send your comments, and hope to see you at one of our upcoming events.

Best wishes,

T. Minshall

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

IfM news

Launch of 'IfM Briefings' event series

We are delighted to be launching IfM Briefings, a new series of thought-provoking, short events that tackle real challenges. These bring the right people together to address problems and share experiences to have a direct impact on improving their work.

Each event is tailored to a defined audience, focusing on a specific topic, hearing from experts in that topic to address common challenges in manufacturing.

Our first event was 'Innovation for Food Security and Sustainability', on 25th June at The Crystal in London, with talks from Tim Minshall, Dominic Oughton, Steve Evans, Gary Punter, Mukesh Kumar and Jag Srai.

To stay up-to-date with upcoming events, please see www.ifm.eng.cam.ac.uk/events/ifm-briefings

IfM hosts final Science2Society event

The Future of Open Innovation Practices Day was hosted by the IfM in Cambridge on 13th February, as the culmination of the European Commission funded project Science2Society.

Science2Society has researched the future of interaction between universities, industries and broader society as a whole. This has included creating pilots and sharing good practices, guidelines and training materials that improve awareness and practical performance in seven concrete university-industry-society interfacing schemes especially affected by Science 2.0 and open innovation.

The final event, held in the Crausaz Wordsworth Building at Robinson College, was opened with a keynote speech from Professor Tim Minshall on open innovation research. The day included interactive workshops and talks which showcased tangible mechanisms for facilitating stakeholder interaction to ensure science's impact on society and the markets.

The Science2Society consortium shared its key findings and recommendations with attendees, to support the ongoing innovation learning process. Find more information about the project at www.science2society.eu.

Vice-Chancellor's visit

It was a pleasure to host Professor Stephen J. Toope, Vice-Chancellor of the University of Cambridge at the IfM on 14th March. The tour took in our robot lab and photonics labs, and the Vice-Chancellor was then given a chance to try out our virtual reality and motion capture equipment, showing how VR is used to teach skills for assembly. We hope that picking up and balancing a stack of IfM mugs in virtual reality will be a memorable experience!

Professional staff recognised with university award

Congratulations to the IfM and IfM ECS professional staff who have been awarded a 2018 University of Cambridge Vice Chancellor's Professional Services Award; well-earned recognition of the amazing work that goes into making the IfM such a friendly, collaborative and innovative place at which to work and study. There were 118 nominations in total this year from across the whole University, of which 49 were shortlisted to the presentation ceremony, with 12 awards handed out. IfM's award was presented in the category of being 'Open, Responsive and Innovative.'

IfM news

John Reddaway, an appreciation

John Reddaway, who has died aged 92, was a Cambridge engineer who pioneered manufacturing at the University, and was the architect of the "Reddaway Plan" which was to shape the manufacturing curriculum. He was the first undergraduate to be sponsored by Westland Aircraft and brought a thorough knowledge of engineering practice to his studies. After graduation he returned to industry before rejoining the Department of Engineering as a Demonstrator – the first rung on the faculty ladder.

The Reddaway Plan became the blueprint for the Advanced Course in Production Methods and Management (ACPMM). This innovative course engaged graduates with engineering practice through visits to companies, lectures from industrialists and demanding industrial projects. The Course continues to flourish as the Industrial Systems, Manufacturing and Management (ISMM).

John will be much missed but leaves major institutional legacies and memories of a warm and modest friend and colleague.

MET Design Show 2019

Student product innovations were on display at the IfM for this year's Manufacturing Engineering Tripos (MET) Design Show on 5th June, with an impressive array of creative concepts brought to life. The design project is a major examinable component of the IfM's third year undergraduate course. Student teams are asked to identify a market need, research the market, develop original design concepts and create a full business plan, as well as building a prototype. In previous years, a number of prototypes have gone into commercial production and won national prizes.

This year's projects included CocoPress, a manufacturing solution to create a biodegradable fibreboard from waste coconut husks (by Taejoo Kim, Ryan Ng and Georgia Semple); PuriFlow, an electrostatic precipitator designed to remove particulates from the air (by Darius Danaei, Sian Evans and James Lee); and Senserene, a pod providing sensory reduction, safety and comfort to children with autism (by Jonathan Heywood, Daniel Hyman and Erica Lee).

There were seven other excellent projects: CoCoal, The River Point Project, Pulpacks, MeatFreeMe, PastePadi, RAD TouchCut Pro and PowerTrak. Read more about all the 2019 Design Show projects at www.ifm.eng.cam.ac.uk/education/met/design

IfM supports GMIS global challenge to find sustainability innovations

On 4th June the IfM hosted the finals of the Global Maker Challenge, a high-profile competition to find innovators and makers with solutions to some of the world's most pressing problems. The Challenge is organised by The Mohammed bin Rashid Initiative for Global Prosperity, in partnership with eight United Nations agencies. The finalists presented their innovations to a panel of expert judges at the IfM, with the winners to be announced in a ceremony in Yekaterinburg in Russia in July.

Over 1,100 entries were submitted from entrepreneurs around the world, from over 80 countries including the United Kingdom. Four main categories included sustainable cities, sustainable energy, rural transformation and zero hunger, and digital literacy – seeking innovations which address the global issues identified in the United Nations Sustainable Development Goals.

Events on the day also included a workshop with Cambridge researchers to help define the challenges for next year, as well as a panel session, chaired by Professor Sir Mike Gregory, with experts discussing social innovation.

Cambridge Science Festival at the IfM

Once again we threw open our doors for an exciting afternoon on Saturday 23rd March, as part of Cambridge Science Festival.

Families came along to experience manufacturing in action, with a chance to take part in a range of hands-on activities, including helping our robots sort chocolate eggs, making your own Lego engineering creations, experiencing virtual reality, seeing the amazing microscopic world, and shooting tin cans with lasers. Tim Minshall talked with an engaged audience about the marvels of 3D printing. Visitors could also have their selfies etched in steel with lasers, and see our PhD students in action in the Pecha Kucha challenge.

Steve Evans talks at prestigious 'Falling Walls'

Professor Steve Evans, Director of Research in the IfM's Centre for Industrial Sustainability, was invited to speak on resource efficiency at the recent 'Falling Walls' conference in Berlin. Falling Walls was initiated 10 years ago, on the 20th anniversary of the fall of the Berlin wall, and provides a unique international platform for leaders from the worlds of science, business, politics, the arts and society to share ideas on tackling major world challenges.

Steve's talk, 'How industrial sustainability can drive economic growth', explored how better use of resources can help address climate change. He emphasised that we don't need to wait for revolutionary new technology, but instead think about how we can become more efficient with existing technologies, and how smarter use of resources is better for business bottom lines as well as for the planet.

Watch Steve's talk at falling-walls.com/videos/Steve-Evans-18318

Dr Jag Srai appointed Chair of Cambridge Global Food Security

Dr Jag Srai, Head of the Centre for International Manufacturing at the IfM, has been appointed as Co-Chair of Cambridge Global Food Security. This is one of the University's eight Interdisciplinary Research Centres (IRCs) (along with Cancer, Conservation, Energy, Infectious Diseases, Language Sciences, Neuroscience and Stem Cells), established as cross-School initiatives to tackle interdisciplinary challenges. Jag replaces Professor Chris Gilligan, and is working alongside Co-Chair Professor Howard Griffiths from the Department of Plant Sciences. Read more about Jag's current work in food security on page 21.

HCL joins the Cambridge Service Alliance

HCL Technologies has offically joined the Cambridge Service Alliance (CSA) as a gold member. A signing ceremony in Cambridge was attended by senior representatives from both organisations including Professor Andy Neely, the University's Pro-Vice-Chancellor for Enterprise and Business Relations and Founding Director of Cambridge Service Alliance, and Ashish K. Gupta, Corporate Vice President, Head EMEA (Diversified Industries), HCL Technologies.

IfM ECS news

ECS key partner in European low-carbon project

IfM Education & Consultancy Services is part of a European project which is bringing together experts and governments around joint challenges to support larger uptake of low carbon grid-related technologies in communities and 'Smart Cities'.

The four-year project, 'Advancing Communities towards low-Carbon Energy Smart Systems', focuses on the upscaling challenges of new technologies and innovative approaches in Smart Cities and a systematic transferability of gained experience and knowledge across regions.

There are four knowledge partners—IfM ECS, Johannesberg Science Park, ENVS at Aarhus University and Energievan.nu—who are responsible for the development of methodologies, evaluation of implementation and roll-out pathways and knowledge dissemination.

Conferences

Internet of Manufacturing – May 2019

The IfM took part in the Internet of Manufacturing, a two-day event in Farnborough helping 'manufacturers looking to lower costs, drive profitability and accelerate digital transformation'.

Duncan McFarlane gave a talk on Digital Manufacturing on a Shoestring, describing how existing and readily available digital technologies could be implemented on a low-cost basis to support growth and productivity in small and medium-sized enterprises. We also hosted a workshop on the IfM's Automation Assessment tool, helping organisations in making decisions about what and when to automate their operations.

See us at...

SMART FACTORY EXPO

Smart Factory Expo
13–14 Nov – Liverpool

The IfM is an Academic Partner for the Smart Factory Expo – the UK's showcase for digital manufacturing. Eight distinct Visitor Zones provide visitors with self-contained platforms to engage with world-class exhibitors, innovative start-ups and experience-sharing sessions from some of the most exciting names in UK manufacturing.

Sign up for your free place: www.digital-manufacturing-week.com/expo

ADVANCED ENGINEERING 2019

Advanced Engineering
30–31 Oct – Birmingham

The IfM will be at Advanced Engineering, the UK's largest showcase on the latest advances in engineering, converging innovations, latest developments and vital information driving efficiency and profitability to enable UK manufacturers to compete and grow in an ever-competitive global market.

Sign up for your free place: www.easyfairs.com/advanced-engineering-2019/advanced-engineering-2019/

Become an IfM member

The IfM has a membership scheme for small and medium sized manufacturers, building close, long-term relationships with members including access to our wide range of expertise.

Some benefits of IfM SME membership include:

- Places for you and/or your employees on SME member training workshops.
- Opportunities to network with peers and IfM staff at social events.
- Opportunities to engage with Cambridge University undergraduate and postgraduate students on potential projects and placements.

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

ISMM Industrial Study Tours

Students from our one-year MPhil course, Industrial Systems, Manufacture and Management (ISMM) went on recent study tours, with one group visiting South Africa and the other touring three European countries.

South Africa tour – perspective from course tutor Simon Pattinson

The industrial study tour is one of the most important learning experiences of the ISMM course. It is a unique opportunity to take up the IfM's mantra of linking management, technology and policy, and to look at the whole manufacturing ecosystem of a foreign country. It is arguably the point in the year when the course members make the transition from being students of manufacturing to young industrialists.

With a population of 56 million, 3 capitals and 11 official languages, South Africa also has a high disparity between rich and poor. ISMM last visited South Africa in 1993, a very different era for the nation. This year, 20 of our ISMM students landed in Johannesburg at the end of March to investigate the current state of manufacturing in South Africa and the vision for the future. We visited 20 selected companies, organisations and universities in Johannesburg, Durban and Cape Town.

Manufacturing, mining and agriculture make up over 20% of the South African economy. Although large, South Africa lacks economies of scale in the domestic market and its location makes it strategically isolated for exporting. Generally, the companies we visited were very successful but most have concerns about the long-term future. Companies such as Hesto Harnesses (automotive sector) are an exemplar of world class industrial practice. But it was clear that some are little more than assembly plants forced to import most of the high-value components. However, all of our company hosts were enthusiastic and many were very passionate about the importance of manufacturing, particularly its social value and impact on the economy. A great aspect of the tour was the number of companies where we were able to 'roam' the shop floor and see the manufacturing processes close up.

Aside from the traditional manufacturing companies, a particularly interesting recent development is Green Cape, an organization based in Cape Town set-up to support green companies. They already have 1,600 members and we were able to visit two companies specialising in sustainable manufacturing.

The Innovation Room at Hesto Harnesses, with Managing Director John Chandler.

There are many learning points from an industrial study tour but the three key themes that emerged during the tour were: governance and black empowerment, resource scarcity and labour relations with a perspective at national level, exploring how South Africa's unique history, culture, and political climate affects industry.

Europe tour – perspective from course tutor Florian Urmetzer

There are 'game changing' contemporary developments in industry, with 3D printing, Industry 4.0 and other technologies revolutionizing the way we produce and integrate consumption. We went to do a reality check: 13 ISMM students travelled across three European countries—Germany, Switzerland and Italy—hunting down the most recent trends and state-of-the-art production facilities.

European manufacturers in the car industry are at the forefront of developing and using elements of modern production systems such as sensors, RFID, automation and digital twins, thereby driving innovation and competition to a level in which efficiency becomes a decisive element. The students from the ISMM course could scrutinize many of these developments in practice during the tour and visited 19 companies from diverse industries.
After the tour, the group summarised their findings and observations in a workshop setting and developed a framework model to establish the characteristics of a modern manufacturing firms' operating environment. In the centre of all companies' considerations is the objective to produce the right product at the right time, in the right place and at the optimal costs. Students identified three main ingredients driving a successful manufacturing business, with different emphasis depending on the industry: the customization of goods, automation of the manufacturing system and digitization of production and internal processes.

During our tour, looking at high value manufacturers, the level of digitization and intelligent analytics was evidently on an exponential rise in production and logistics systems. Manufacturers such as SICK AG, Lamborghini, Porsche and ABB are at the forefront of innovating, defining, and implementing their own custom recipe for a digitally enabled factory of the future. For example, the cyber-physical production system of SICK AG, with only 13 employees, is capable of producing 1.5 million finished products per year with 1.5 million variations. Lamborghini and Porsche abolished the traditional rigid assembly line and introduced a system where every car body is transported on an autonomous guided vehicle.

ISMM students visit Lamborghini during the European study tour.

During the tour, students saw evidence that the best modern manufacturing systems must be designed with an integrative approach by balancing customization, automation and digitization according to customer demand and by development of internal capabilities.
A suitable governance structure that enables innovation and creates an intrinsic motivation to pursue unexplored pathways will drive a firm to success. These were valuable insights for our students to gain in real industrial settings, and as always they returned full of inspiration to explore the ideas further.

Has manufacturing been underestimated?

How much does manufacturing really matter to the UK's economic prosperity? National statistics report that manufacturing activity contributes only 10 percent to GDP, with a trend towards deindustrialisation over the past decades seeing services replacing manufacturing as the future engine of growth. But a new report by Dr Jostein Hauge and Dr Eoin O'Sullivan of the IfM's Centre for Science, Technology and Innovation Policy (CSTI) explains why this picture is misleading, and why the real economic value of manufacturing is in fact significantly higher.

The manufacturing sector plays a significant role in the UK economy. As measured in the national accounts, it provides over 2.7 million jobs, makes up 49 percent of UK exports, and contributes 66 percent of all UK R&D business expenditure (Office for National Statistics, 2018). However, based on current measurements, manufacturing contributes only around 10 percent to national GDP, apparently dwarfed by the services sector which makes a 70 percent contribution to GDP.

But new research indicates that the picture is more complex than these figures suggest. Emerging technologies, business models and value chain structures are changing the manufacturing landscape. There have been radical alterations not only in how we make things, but also in how we innovate and in how we capture value from manufacturing-related industries. As manufacturing evolves, so too do definitions of manufacturing and industrial systems. In turn, policymakers need new ways to assess the value of manufacturing activity.

CSTI's Jostein Hauge explains:
"The difficulty lies in trying to measure manufacturing as a single category. It is inherently more complex. Economic value of manufactured goods increasingly depends on activities that are officially categorised as belonging to other sectors of the economy. A range of manufacturing-related services are excluded from the manufacturing category."

For the purposes of developing industrial strategy, policymakers need to understand manufacturing in a broader context, with the ability to identify interdependencies across activities which are currently separately categorised.

> "This report is a clarion call for politicians of all parties to update their understanding and recognise the central importance of manufacturing not only to local regions but to the wider UK economy as well."
>
> SEAMUS NEVIN, CHIEF ECONOMIST, MAKE UK

Clare Porter, Head of Manufacturing at the Department for Business, Energy and Industrial Strategy, comments:

"The official statistics fail to incorporate fully the role of UK manufacturing in supporting national economic competitiveness and growth. In particular, the official manufacturing statistics do not include the additional value added or jobs generated by services across manufacturing value chains. Many of these services would not thrive, or even exist, without UK-based manufacturing.

"It is important that policymakers understand this bigger picture and the dependencies between recorded manufacturing activity, industrial services and capabilities so we can develop policies and programmes that will support long term UK industrial competitiveness and growth."

A new report 'Inside the black box of manufacturing' by Jostein Hauge and Eoin O'Sullivan reveals that the economic contribution of manufacturing is more significant than is conveyed by conventional methods of counting. The report discusses how manufacturing is defined, how it is changing, its interdependencies, and recommendations for policymakers shaping the UK's industrial strategy and policy agenda.

What is 'manufacturing'? A systems view

So how should we be more accurately conceptualising and counting manufacturing in the economy?

National manufacturing activity, as normally reported within the national accounts, is measured by counting the output of firms whose main industrial activity involves the transformation of materials or components into new products, and/or the assembly of components or subsystems into new products.

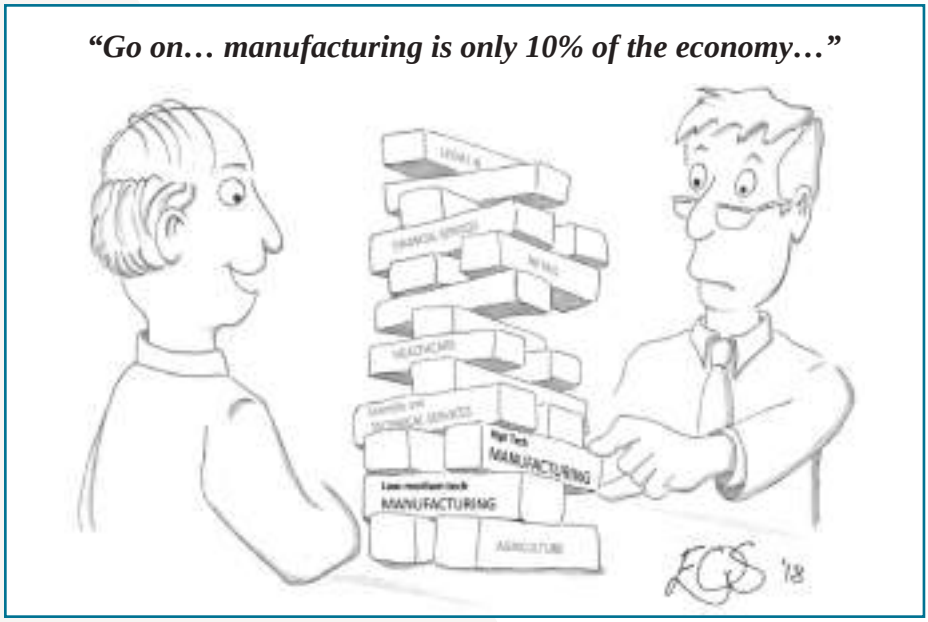
But a key challenge for policymakers and national economic statisticians is that the economic value of many manufactured goods depends on activities beyond factory-based production. Most production systems today are highly complex, and rely on contributions from a range of 'industries', as we traditionally think of them.

As Eoin explains:
"Our aim is to highlight the systems-nature of manufacturing. Think about the functioning of a manufacturing system like the functioning of a complex organism, like the human body. The functioning of the human body relies on cooperation between interdependent biological sub-systems — like the circulatory system, the digestive system, the immune system, the nervous system, the muscular system, the respiratory system, and so on. Just like the human body, the functioning of a manufacturing system relies on cooperation between interdependent sub-systems as well.

"The central value chain, which consists of R&D, design, production, distribution, and after-sale services, needs timely provision of technical services, like analysis, testing, and logistics. It also needs timely provision of specialist professional services, like regulatory services, intellectual property services, investments services, and consultancy services. And it needs supply of materials, components, and other manufactured inputs, like machinery, equipment, and tools."

Problems with current classification

In the UK, economic activities are classified using standard industry classification (SIC) codes. This means that a company that both makes and delivers a product will be classified into either manufacturing or services, not both, depending on the number of people working in each category. Consequently, shifts in the number of companies counted as 'manufacturing' can be caused by changing outsourcing arrangements rather than an actual change in the economy's production structure.



Another cause of distortion is that productivity in manufacturing grows faster than that of services. In many operations settings, more units can be produced by a smaller number of people. A consequent shift in employee balances – fewer needed in production, more needed in related services – can suggest that manufacturing's value has dropped, whereas the reality is that its productivity has increased.

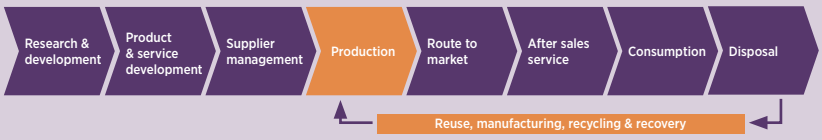
A UK government report estimates that up to 10 per cent of the fall in manufacturing employment between 1998 and 2006 in the UK may be due to this reclassification effect.

> Part of the manufacturing decline can be explained by the fact that manufacturing has higher productivity potential than services, not because it is 'less important'.

To compound the issue, the current classification system reflects an increasingly outdated understanding of what activities are involved in manufacturing. Advanced manufacturing involves new types of factory input, production stages and industrial processes, including integrated software solutions, design of synthetic materials, and recycling and reuse of materials, to name a few.

Crucially, there are many activities classified as 'services' which actually require manufacturing-specific technical knowhow, like R&D, industrial design, analysis, and testing. Additionally, professional services, like regulatory services, intellectual property services, investment services, and consultancy services, are increasingly tailoring their needs to specific manufacturing industries.

Jostein comments: "We argue that many of these services (at least the technical services) should 'belong' to the manufacturing sector for the purpose of industrial strategy."



Note: Within this value chain some elements are repeated many times, for example as components come together to build a complex product. There are also feedback loops which may vary for different sub-sectors.

Why does this matter?

Seamus Nevin, Chief Economist at Make UK, states:
"Despite the common sense of declinism, manufacturing businesses contribute nearly 3 million mostly high-paying jobs, half of UK exports, the bulk of this country's R&D spend, and the UK is today the 9th largest manufacturing economy in the world in GDP terms. And, as this report shows, those figures are probably significant underestimates.

"An increasingly outdated understanding of what modern manufacturing actually is means policymakers have neglected the sector in the misguided belief that services, not manufacturing, is where the future potential for innovation and productivity growth lies. This report is a clarion call for politicians of all parties to update their understanding and recognise the central importance of manufacturing not only to local regions but to the wider UK economy as well.

"The Government has set out a modern industrial strategy which will be at the centre of the UK economy post Brexit. It is now essential that there is cross party support to deliver on this to ensure we meet the new technological challenges of digitisation, as well as the societal challenges to which manufacturing, science and engineering will be at the heart of solving."

Eoin agrees:
"If the economic contribution of manufacturing is underestimated, the implications could be significant. First, industrial strategy will fail to target all those firms that should be targeted. Second, if manufacturing does not appear to be important for the economy, it could mean that industrial strategy will become neglected on the government's policy agenda. A well-designed industrial strategy is vital for the prosperity of the UK economy."

Understanding the problems with current measurements raises important questions.

First, has the extent of deindustrialisation been overstated?
In the UK, the gross value added of manufacturing in GDP has declined from 17 percent in 1990 to 10 percent in 2017. This clearly indicates that the UK is going through a process of deindustrialisation. But how accurate is this rate of decline?

Jostein comments:
"We are not arguing that deindustrialisation in high-income countries, like the UK, is not happening. But our conclusion is that the manufacturing ecosystem is larger than what the industry classifications data on manufacturing reveal."

Defining manufacturing...

Second, is the future potential of manufacturing being underestimated?
The trend of deindustrialisation in the UK and other high-income countries has spurred a discourse which claims that services, not manufacturing, is where the future potential for innovation and productivity growth lies. This view fails to shed light on interdependencies between manufacturing and services, but could have a major influence on national investment decisions.

Third, how do we interpret the likely impact of digitalisation?
Digital technologies, such as artificial intelligence, additive manufacturing, and the industrial internet of things, are becoming more pervasive in manufacturing processes. However, as the report points out, evidence of the impact of how these technologies are affecting manufacturing is scant, which signals a need for research to devote more attention to digitalisation.

More accurate numbers to inform industrial strategy
The report's main recommendation is that for the purpose of industrial strategy, the current classification system needs to be reorganised. Firms should be associated with those sectors of the economy to which their productive capabilities contribute. This means that, for example, Arm, which is a UK semiconductor and software design company, should not be simply classified as a 'services' activity, but should be identifiable as a critical part of the UK manufacturing industry ecosystem.

Jostein concludes:
"Essentially, we are arguing for a system of analysis that is more useful for policymakers than the existing system of industry classification codes, that can show how firms have self-organised around a common economic value proposition.

"Policy therefore needs to have a more holistic sense of the system. Industrial strategy should be designed with not only manufacturing firms in mind, but also all the services firms that are part of and serve industrial systems.

"It is essential for policymakers to invite these services firms to the table when they conceptualise their national industrial strategy. We also hope that this will provide compelling reasons for policy practitioners and national economic statisticians to believe that manufacturing still is and will keep being an integral driver of technological development, productivity growth and economic prosperity."

The report *Inside the black box of manufacturing: Conceptualising and counting manufacturing in the economy* has been prepared for the UK Department for Business, Energy and Industrial Strategy. Find it at www.ifm.eng.cam.ac.uk/insights/inside-the-black-box-of-manufacturing


Dr Jostein Hauge


Dr Eoin O'Sullivan

The practical impact of digital manufacturing

Is it possible to identify a real economic impact resulting from the 'digital revolution' in manufacturing? Governments in a number of countries have made efforts to boost their national economies through investment in digital manufacturing. But is there yet evidence of any resulting upturn in productivity, gross value added, or employment?

A recent study for the UK government by leading Cambridge academics indicates grounds for optimism. Indeed, the findings provided key evidence for £120 million funding boost announced by the government in late 2018. Dr Carlos López-Gómez, Head of the IfM's Policy Links Unit, explains more...

Over the last few years, there have been many predictions made about the potential impact of the digital revolution on manufacturing and the wider economy. The forecasts point to a potentially disruptive effect of digital technologies across all aspects of industries – from the way in which products are made, the types of jobs manufacturers are able to provide, and the functionalities offered by digitally enabled products and services.

In keeping with this outlook, the Made Smarter Review for the UK government in 2017 projected that the adoption of digital technologies in UK industry could lead to a 25% increase in productivity by 2025.

But can we yet point to evidence of impact that companies can relate to? Innovate UK (IUK) recently commissioned the Policy Links Unit and senior academics at the Institute for Manufacturing, University of Cambridge to evaluate the evidence on the impact of digital manufacturing. The resulting report, 'The practical impact of digital manufacturing: Results from recent international experience', analyses how digitalisation technologies are actually being deployed in key manufacturing countries, and the results for the firms deploying them. The aim was to identify both expected and observed results of digitalisation in manufacturing, drawing on examples from around the globe.

IUK's primary objective was to build the evidence base to inform investments in digital manufacturing technologies under Wave 3 of the government's Industrial Strategy Challenge Fund - part of government's Industrial Strategy, the long-term plan to raise productivity and earning power in the UK. The UK government has made a commitment to increase funding in research and development by £4.7 billion over 4 years to strengthen science and business nationally.

The predicted impact

National governments have attempted to estimate for the expected economic impact of digitalisation on manufacturing, using national-level indicators such as productivity, value added and jobs.

- **Value added:** The most common indicator used in the sample of countries surveyed is value added. Estimates vary significantly, reflecting differences between the size of national economies (for example, Germany predicted €425 billion value added compared to Canada's €22.6 billion), but it should be noted that these figures very much reflect differences in the sizes of the national economies.
- **Productivity:** Germany's government has estimated productivity gains of up to 30% by 2025, and Singapore has estimated a 30% improvement by 2024. In Japan, the government estimates that growth in labour productivity in manufacturing could be increased by more than 2% annually, citing as a key driver an expected doubling of robot use by 2020.
- **Jobs:** Despite common perceptions about the potential negative impact of digitalisation on jobs, all estimations identified forecast that digitalising industry will also lead to the creation of new jobs. Spain estimated 1.25 million new jobs would be created over five years.
- Qualitative measures are also regularly cited by governments, including benefits to competitiveness, business confidence, and sustainability.

However, these evaluations have so far been almost entirely focused on future predictions, with attempts to quantify

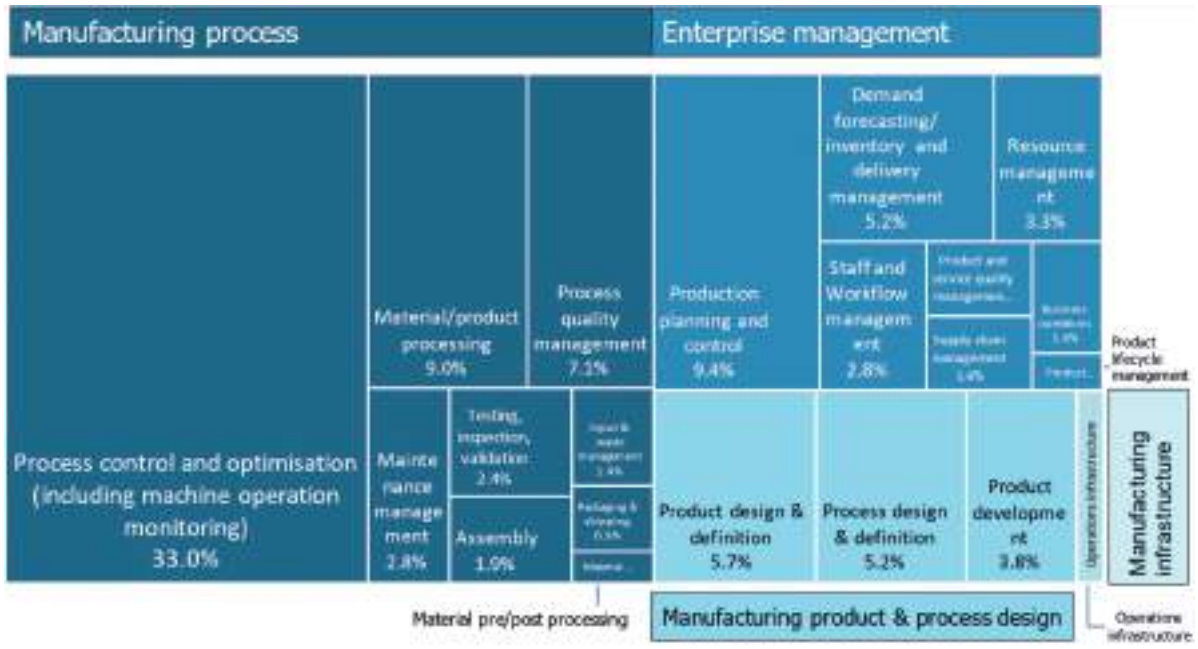


Figure 1: Image shows that most manufacturing firms are applying digital technologies in the manufacturing process itself, primarily to improve process control and optimisation

the expected impact of digital adoption, mainly based on rough macroeconomic extrapolations and survey data.

Very few countries have published data on real (observed) impact of digitalisation across their national economies. Singapore and Korea are notable exceptions - both reporting the same level of improvements in manufacturing efficiency in firms (around 30%). In Korea, systematic efforts have been made to evaluate the firm-level impacts of digital adoption on over 3,000 firms supported by a major national programme, the Korea Smart Manufacturing Initiative.

Policymakers making investment decisions are better equipped if they can refer to actual evidence of *observed* impact alongside projections. But so far there has been a lack of availability and analysis of such evidence.

For IUK, making the case for investment from the Industrial Strategy Challenge Fund to be put into digitalisation of manufacturing required evidence-based research to unpick how the digital revolution is playing out in the major manufacturing economies. IUK also wanted to understand if there are lessons the UK can learn from other countries, and the types of digital transformation initiatives that are likely to deliver impact. This required deeper investigation into the manufacturing activity at company level.

The observed impact

To do this, the team developed a common framework to collate and compare data from across different countries and different types of organisations. This was no small feat, given the variety of terminology used and lack of commonality in how impact and productivity are measured.

The study also identified which activities are being prioritised for digitalisation investments by manufacturing firms, and where the business value is being created.

Much of the data was drawn from small and medium size enterprises (SMEs), which is the focus of the majority of funding initiatives worldwide. The richest sources of data were from key manufacturing countries such as China, France, Germany, Korea, Japan, Singapore, the US and Canada.

The team identified over 1,000 use cases from across these economies, and selected 200 companies (all participating in government-backed initiatives supporting digitalisation) for closer study. In each of these 200 cases, the team examined the business areas being prioritised, the types of digital applications companies were using, and the benefit they reported from digital adoption.

Where are manufacturing firms using digital technologies?

Digital applications and solutions were classified according to the functional areas where they were deployed, as shown in Figure 1 above.

There was a heavy emphasis on prioritising digitalisation at the manufacturing process level. The firms analysed were found to be prioritising the following areas:

- 33% of the cases were prioritising digitalisation to support process control & optimisation
- ~ 9.4% to support production planning & control
- ~ 9% to support material/product processing
- ~ 7.1% to support process quality management
- ~ 5.7% to support product design & definition

Where are firms getting the most value from digitalisation?

The team then analysed the impact reported by firms from their digital investments, across various measures of business value.

The top five business areas benefitting most from digital initiatives include:

- Reduction in labour costs (median >55% improvement)
- Reduction in defects and costs (median >45% improvement)
- Reduction in material costs (median >45% improvement)
- Increase in outputs (median >30% improvement)
- Improvements in delivery and service performance (median >30% improvement)

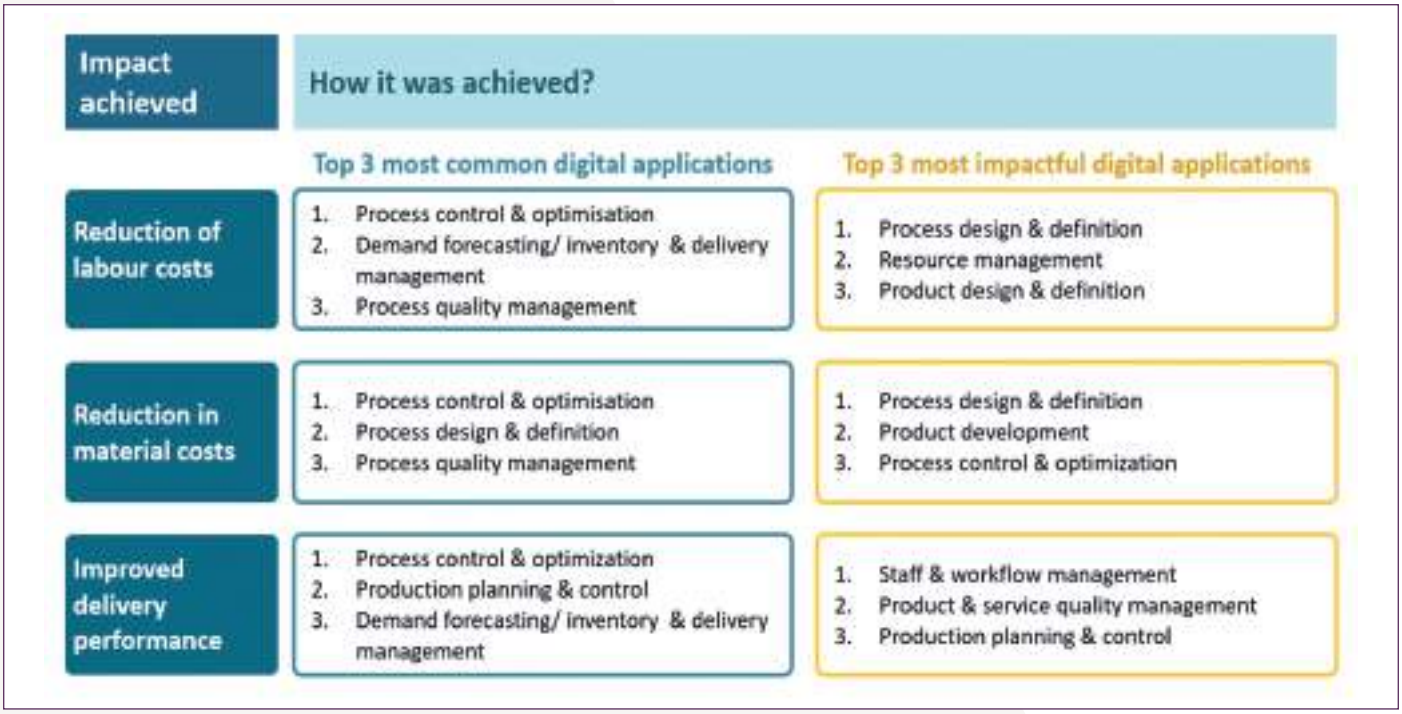


Figure 2: The most popular digital application is not always the most valuable

Interestingly, however, the evidence shows that the applications where most companies focused their digitalisation efforts are not necessarily those that delivered the most benefit. For example, companies that reported a reduction of costs were most likely to be using digital applications focused on process control and optimisation (Figure 2 above). However, the impact was bigger when they used applications aimed at improving process design and definition.

Five strategic insights

The analysis in the report enables a number of insights which can inform strategic decision-making, both for firms and for policymakers. Five key insights are:

1. Supply chain-level opportunity:
We found that most digitalisation implementation projects are focused within one company, often with a single application, and very few encompass supply chains or networks of companies. The value of achieving digitalisation across supply chains is therefore not yet being exploited. The success of such supply chain digitalisation projects is likely to depend on support being offered to SMEs to make the costs and uncertainty manageable. The international experience suggests that this can be enabled through support from both government initiatives and larger supply chain partners.

2. Information for selecting priorities:
We also found that the areas prioritised for digitalisation are not necessarily the same as the areas that can deliver most business benefit to organisations. There is a dominant focus on production processes and lines. As more evidence becomes available, it should become easier for more informed decisions to be made. This includes better understanding of which digital applications are more relevant to different sectors.

3. More than just technology:
Looking at how technologies actually find their way into firms' operations is vital for achieving effective digitalisation. However, we found that often technologies are seen as the end in itself. The technical, managerial and contractual barriers that firms face to gain value from them often come as an afterthought. Considering these aspects early in the design of support programmes is critical to ensuring their effectiveness.

4. Implementation lessons:
The report also provides insights into implementation strategy. The team looked at digitalisation initiatives in other countries, and talked to people leading them, to understand better the practical considerations for successful investment programmes. National roll-out efforts in the UK could benefit from better understanding effective practices (and pitfalls) from international practice.

5. The unique UK opportunity:
For the UK, there are a number of strategic considerations, such as where investment could help the UK genuinely gain a competitive advantage. The report provides insights for UK policymakers into opportunities to go beyond just direct comparisons with other national economies, and to think about how the UK can differentiate itself.

The evidence gathered provided IUK with key evidence for inclusion in their business case, which was successfully awarded £120 million investment for 'Made Smarter', announced in autumn 2018.

Report
The Practical Impact of Digital Manufacturing: Results From Recent International Experience (www.ifm.eng.cam.ac.uk/uploads/Content_Images/IfM_IUK_Interim_revised.PDF), was commissioned by Innovate UK and written by the IfM's Policy Links Unit, led by Dr Carlos López-Gómez, with contributions from researchers, including Professor Duncan McFarlane, Dr Eoin O'Sullivan and Dr Chander Velu.

Dr Carlos López-Gómez

Resource efficiency:

Can sustainability and improved profit go hand-in-hand?

Moving towards improved sustainability might seem daunting for manufacturers. What should be prioritised, will it be a distraction and sink resources, and is any of it affordable? But what if you had a clear business case to show that improved sustainability would also help your bottom line? And what if that could be achieved with today's existing technologies and know-how, rather than waiting for a silver-bullet solution to be invented?

Professor Steve Evans, Director of Research at the IfM's Centre for Industrial Sustainability, shares his insights into how resource efficiency can be good news for your profit margins as well as the environment.

Did you know that only 50% of edible food we produce is actually eaten? Or that only 10% of processed material reaches the customer? Just think about that: an eye-watering 90% of the resources we process to create goods are not reaching the person for whom they are made.

There are examples of inefficiency and waste all around us. For example, in the UK (a tiny island with a comparatively excellent motorway system) trucks on average carry only 27% load factor – so 73% of truck haulage capacity is not being used.

Factories are responsible for an estimated 36% of greenhouse gas emissions globally, and often the carbon footprint of manufacturing operations is closely related to how efficiently they operate.

It's clear that we need to be working towards reducing such inefficiencies. But is it realistic to think we can take significant steps towards addressing these issues without sinking bank-breaking costs in the process?

Improving efficiency without reinventing the wheel

Rather than waiting for new revolutionary technological solutions, what can we do with the knowledge and capabilities already at our disposal? This is one of the main questions we need to ask about industrial sustainability, and an issue I regularly discuss with industry leaders and policymakers, because the solutions are often more about organisational strategy, culture and behaviour than about technical capabilities.

Many of the answers may surprise you. When analysing efficient use of resources, we're talking about how we use energy, water and materials, and how we minimise waste and pollution. Economic principles would suggest that businesses will seek and find the most efficient ways to operate in order to drive down costs - and resource efficiency is imperative for this. And yet, the evidence shows that most companies are not using resources efficiently, and often are in fact unaware of where their inefficiencies exist, even if there are immediate actions that could be taken that do not rely on heavy investment.

Why is this worth doing? Take the example of Toyota In the UK, Toyota has been reducing the energy it uses to manufacture a car by at least 8% every year for 14 years, resulting in over 70% reduction over the period. The company can now make four cars for the energy it used to take to manufacture one car 14 years ago. Crucially, Toyota has done this by identifying improvements to energy usage, not by depending on a major new technology to revolutionise the business.

If manufacturers moved just half way from their current resource usage towards the usage of the most efficient companies in their own industry, our research indicates that the impact in manufacturing would be 12% increased profit, 15% more jobs and 5% reduction in greenhouse gas emissions.

An example from the cement industry

The cement industry is the second most intense industrial producer of CO2, responsible for around 5% of global emissions. If it were a country it would rank as the third highest producer of emissions after China and the US. It is an industry of low margins and high capital, resulting in many plants being decades old and inefficient.

The Hanson Ketton cement plant in Rutland, UK has used alternative fuels since 1991. Researchers worked with a number of plants to develop a new metric to improve fuel mix, leading to substantially reduced emissions and costs.

Research by my colleague Dr Daniel Summerbell from the Centre for Industrial Sustainability has investigated the scope within existing plants to improve their efficiency through changes which do not rely on capital investment, through analysis of performance variations.

The research looked at three cement plants in the UK, using plant data and computer modelling to understand the impact of fuel mix on performance, particularly the fuel-derived CO2 emissions.

The increasing use of alternative fuels has been a defining trend in the cement industry over recent decades, which has had clear benefits for plants, primarily in reduced fuel costs as well as reduced carbon footprint. However, because of the diversity of materials being used as alternative fuels, the exact relationship between thermal substitution rate (TSR) and environmental impact in terms of CO2 emissions is not always clear. Accordingly, research by our team at the University of Cambridge with Hanson Cement has

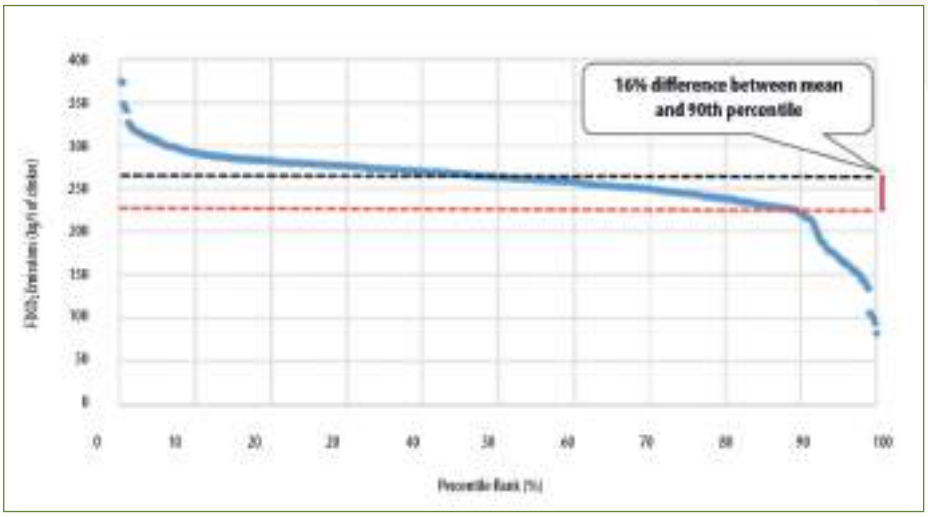
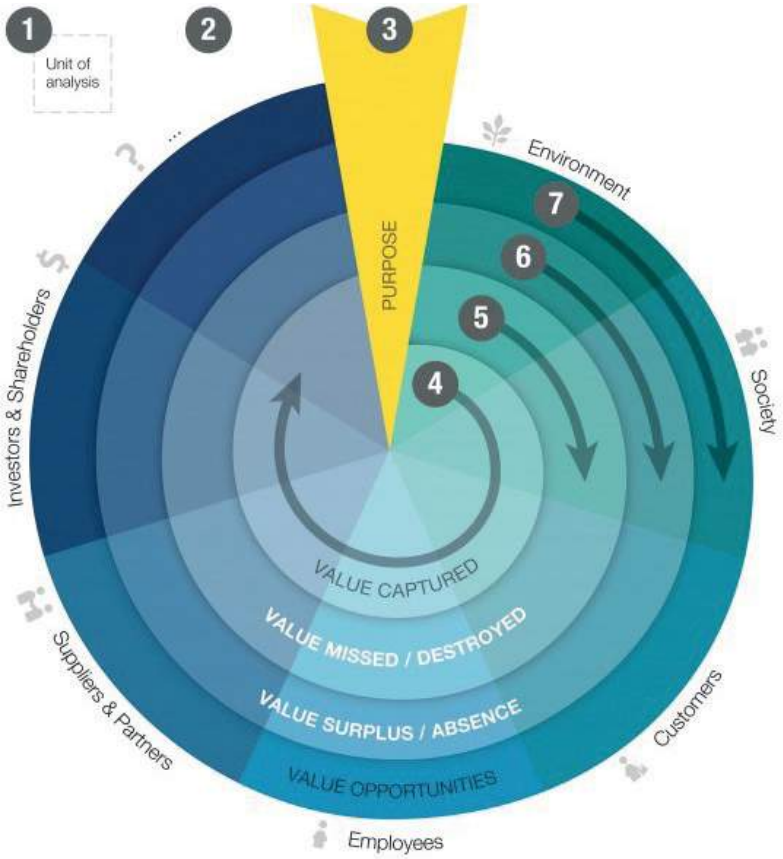


Figure 1: Variation in fuel-derived CO2 emissions at a cement plant.

sought to investigate the uses and the limitations of TSR as a metric. The research has found that improving fuel mix, by the use of a newly-developed metric, could reduce fuel-derived CO2 emissions by 10% or more. While such improvement is subject to availability of appropriate fuel and operating conditions, the low capital requirement makes it very attractive to industry.

Figure 1 above shows the variation of fuel-derived CO2 emissions in a cement factory, produced to make a day's worth of cement. The research compared the median performance of the plants with their 90th percentile best-observed performance. This gap was found to be large: essentially, there can be a huge difference in emissions between the best day (around 190kg emissions) and the worst day (around 340kg emissions). It indicates that standardising performance could reduce fuel consumption by ~6% and fuel-derived CO2 emissions by as much as 16%, all while operating within the existing capability of the plant.

As Daniel explained:
"Through uncovering this enormous variation, we were able to work with the plant to analyse where the variation was happening, and model the operations in detail to identify the causes. We found that the most significant variables were fuel mix and excess airflow, both of which could be adjusted using existing systems in the plant to improve efficiency. We estimate that at projected prices for 2030, the saving could be worth 1.7m euros per year in carbon prices alone for a single plant."



The Cambridge Value Mapping Tool

How do we get there? Three strategies

So how can companies and their supply chains work towards improved resource efficiency?

At the Centre for Industrial Sustainability we are working on a number of ways to help manufacturers use resources more efficiently. We identify three key strategies as follows:

1. Understanding value opportunities
We need to start by pinpointing places where resources are wasted, and where opportunities are missed for creating value. As demonstrated in the examples from Toyota and from the cement industry, better use of resources is frequently a source of improved profit margins.

We have developed the Cambridge Value Mapping Tool to help companies recognise where value is being captured, and where it is not (which we refer to 'uncaptured' through missed, destroyed, surplus or absent value), using a structured and visual approach. We use this to analyse exchange of value through the lens of each stakeholder in the business network, with the natural environment and society each being given its own voice.

2. Scalability
Beyond identifying where resources are squandered or where value is not captured for an individual company, we also need to understand how to scale the findings across industry.

For industrial sustainability to be more widely achieved, it is essential that we don't just work in siloes where one company works out a clever trick and then says 'job done'. We need to understand how to scale these solutions.

There's an imperative to find solutions that work at scale and increasingly at speed. If we are to hit the targets set out in the United Nations Sustainable Development Goals by 2030, and the Paris Agreement, we need to work towards significant change at the rate of 6% or above improvement per annum of energy, water and material efficiency as well as reducing waste.

Scalability is also about cooperation across industry. Change can be achieved more effectively if organisations collaborate and learn from each other to achieve overarching goals that are in both the individual and the collective interest, by understanding how other companies are making efficiency improvements. This can be supported by engagement from policymakers.

3. Deploying simple tools
To make efficiency improvements more achievable for manufacturers, scalable, practical and easy-to-use tools are required. Resource usage needs to be more visible, then ways to address it made straightforward and measurable.

We've been collaborating with Manufacture 2030, an organisation which provides a cloud-based platform called M2030 Bee which helps manufacturers use less energy, water and materials, and thereby cut operational costs and environmental impact. This type of approach, well researched and carefully implemented, will make a valuable difference.

We have developed other tools and methods in the Centre for Industrial Sustainability that further support resource efficiency. These include our Zero Loss Yield Analysis (ZLYA), helping manufacturers measure their actual yield from raw materials compared to their expected yield. The results from YLYA are often enormously illuminating – a recent manufacturer we worked with discovered that their actual waste was 14 times greater than expected and was able to take steps to reduce it.

Continued efforts to help manufacturers to use resources as efficiently as possible can certainly result both in reduced carbon footprint and in substantial financial benefits.

If you would like to find out more about deploying tools and techniques in your own manufacturing operations, or attend a CIS workshop, contact Ian Bamford at imb31@cam.ac.uk.

[i] See www.nextmanufacturingrevolution.org for more background on figures quoted in this article.

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Professor Steve Evans

Grass-root circular economy through creative waste innovation

Nurturing local entrepreneurs to develop new products from waste materials

Led by Dr Curie Park from the Centre for Industrial Sustainability, recent IfM projects in Thailand utilised local industrial waste and ocean plastic waste to develop sustainable products and services and identify circular economy business opportunities for local entrepreneurs.

In the drive towards a circular economy and climate change mitigation, better caretaking of waste plays a key role. How do we reduce the waste we send to landfill and to the oceans, and what do we do with the waste that is already out there?

While the current linear economy system of 'take-make-use-dispose' generates more waste as the global population grows, there is increasing pressure on resources, leading to material scarcity. But there are ways to change this trend: if waste can itself be reused or recycled, there is an opportunity to use it as part of the solution to address material scarcity – taking a 'circular' approach. Transitioning from a linear economy to a circular economy makes good economic sense, using a closed loop of material flow to recapture the value.

While the concepts of 'circular economy' are widely discussed and studied, many of them at still at a theoretical level with little supporting evidence or best practice at a replicable scale yet. Furthermore, it is hard to find research on emergent, bottom-up level waste management. A majority of circular economy research is focusing on top-down approaches from an organisational point of view. Hence, more robust methods for applying circular waste management at the grass roots level must be identified, tested and rolled out at scale. A Practice-based research would address the gap and provide templates for successful impact creation.

Working with communities to recapture value from waste

Dr Curie Park from IfM's Centre for Industrial Sustainability (CIS, PI: Steve Evans) has been leading three such research projects in Thailand and Sri Lanka, with different groups including large manufacturers, SMEs, students, local communities and entrepreneurs.

The latest project, funded by the GCRF (Global Challenge Research Fund) Global Impact Accelerator Account Impact Fund, worked with the local community and businesses in Na Jomtien, a coastal village in an area popular with tourists, near the larger resort of Pattaya in Thailand. Curie explains:

"Thailand has a real problem with plastic pollution, and has been ranked the world's 6th biggest ocean plastic polluter in the world. There are limited waste management systems at the national level, combined with very high consumption of plastic packaging, and a lack of awareness of the harmful impact of littering."
Curie, with Ian Bamford, Commercial Director at CIS, ran workshops in Na Jomtien with local organisations, municipal officers and village representatives with a strong emphasis on community engagement throughout. The first activity was beach cleaning at Baan Ampur.

Ian describes the activity:
"We had 23 participants combing through the sandy beach and an artificial breakwater structure, including Cambridge researchers, Thammasat University students, employees from local businesses, and Na Jomtien villagers and volunteers. We collected 41 bags of plastic debris within just 90 minutes, which highlights the extent of the issue. This hands-on activity provided the participants and researchers with an excellent opportunity to experience the magnitude and the breadth of the marine plastic waste issues."
Following this, an 'ideation' workshop was

Collecting plastic waste at Baan Ampur, Thailand

held to consider how the waste could be repurposed, with local participants, students, farmers and businesses based on the beach, as well as the Thai Plastics Institute.

In parallel, the project incorporated further experimentation and testing of 'Glasstic' material, an industrial waste plastic and glass composite for construction – an innovation developed during one of Curie's previous Newton Fund research projects. A range of commercial-level property testing was conducted to confirm the technical competitiveness of Glasstic, working with a local researcher, Ronnagit Kobchaikul from Thammasat University. He was commissioned to take a charge of prototyping and testing with the local partner company PTTGC, with results demonstrating superior moisture contents and water absorption rate compared to its substitutes such as plywood and fibre cement board. In addition its aesthetic potential was recognised for providing unique characteristics.

Glasstic – a composite made from waste materials.

The local Na Jomtien group identified 20 local-specific challenges and generated 56 new ideas for the ocean and community plastic waste upcycling, which directly address the challenges identified. Curie adds: "We then brought the participants together to focus on one or two prioritised ideas each, and follow an 8-step process to evaluate the opportunities, business models and pilot planning using the CIS frameworks. Finally, three of the original ideas were selected and further developed into concrete pilot plans, supported by a local steering committee."

The aim is for these business ideas to develop into revenue-generating commercial projects, which will benefit the local economy. They will serve as a model for public education, showing the viability of the circular economy.

The ideas were grouped into two streams. The most favoured ideas for the partner company to take forward for commercial development were roofing, outdoor furniture and fencing. Key advantages included the stability of the waste feedstock and the scalability to an industrial volume. The roofing and fencing ideas are particularly of high interest thanks to their high technology readiness and the relevance to the nature of the partner company MQDC's main business area of property development and construction.

Community groups from Na Jomtien and Baan Ampur favoured ideas such as Stand-up Paddle Board (SUP) for waste collection, compost bins, flower pots and recycling bins as they are closed linked to the daily needs of the community members. In particular, the Stand-Up Paddleboard for waste collection in the sea was an idea evolved by Ms Amara Wichithong, a local entrepreneur-cum-activist who has worked on addressing marine plastics issues in Na Jomtien area for the last couple of decades. As a former windsurfing world champion, she's been working on organizing beach cleaning with the surfing school customers, local children and Olympian colleagues, and has brought huge energy to the project.

In terms of long-term impact, Curie comments:

"There are several ways in which we expect to have a lasting impact. The project created the momentum at local level for actions to address the waste problem, and an understanding of how to generate real business ideas from the circular economy. We created motivation to change behaviour. The fact that an

"Using a lifecycle approach, it has been estimated that a 10 to 15% reduction in global greenhouse gas emissions could be achieved through landfill mitigation and diversion, energy from waste, recycling, and other types of improved solid waste management."

(UNITED NATIONS ENVIRONMENT PROGRAMME, GLOBAL WASTE MANAGEMENTOUTLOOK 2015)

Thailand – a few statistics:

- 513,120 km2 (198,120 sq mi)
- Over 68 million people
- 2nd largest economy in Southeast Asia
- Manufacturing, agriculture & tourism are the leading sectors
- Poverty declined from 67% in 1986 to 7.1% in 2015
- Population is increasingly urbanised, at 49.2% in 2017.
- GDP growth rate of 4.1% in 2018
- Generates 26.77 million tonnes of municipal solid waste and 16.05 million tons of untreated industrial waste every year.
- Thailand's economy is export-dependent, contributing about 60% to GDP.
- Thailand is ranked 6th in the world for generating plastic pollution in the oceans.

Sources: World Bank, Asian Development Bank, Trading Economics, Atlas, Science journal.

international project team came to the village to bring the local individuals together and to draw their local wisdom boosted their confidence and hope for a positive change at scale.

"The exciting part was its genuine interdisciplinarity. The project attracted more and more partners as it unfolded. The existing partners invited more of their connections including NGOs, government contacts and start-ups.

"It also demonstrated the step-by-step actions needed to put waste innovation ideas into practice, including transfer to locals of key knowledge and business model development skills using the CIS frameworks. Within the first month since the completion of the project, the industrial partner MQDC cemented at least seven different community waste upcycling projects."

Award-winning student innovations

Another of Curie's pilot projects was the Creative Hub for Waste Innovation, which was jointly supported by the Thai and UK Governments with the award of a Newton Fund Institutional Grant, and run in collaboration with Thammasat University and three local manufacturing SMEs who were trying to improve waste management.

The project involved working with SME manufacturers to reclaim and upcycle waste materials from their processes. In Thailand, 93% of waste from SMEs is not being properly treated. Taking waste directly from their production processes is more efficient than recycling or disposing of it, so this project focused on how waste materials could be directly repurposed into new products. To gain insights into some of these issues at first hand, the cohort of Thammasat students and researchers visited seven local SME manufacturers to get a better understanding of their processes, the type of waste materials created, and the issues around disposal of waste.

Working in small teams, the students were challenged to identify how they would create a new product from waste materials – choosing from plastic, wood or glass.

They followed a process facilitated by Curie, using a selection of CIS tools and the 'Design Thinking' framework, to generate and develop product designs and business models.

Three of the teams were given the opportunity to present their innovations at an investment pitch as a part of the Bangkok Design Week 2019. Ed-Kid, a DIY puzzle toy created using upcycled HDF waste, was voted as one of the top three Best Creative Business Awards 2019. Curie explains:
"This was a really exciting finale to the project. Ed-kid is a great product - using the narrow offcut pieces from a local car factory, the team developed small parts that children can assemble into buffalos and rice paddies symbolising the 'Thai agriculture scene'. It really worked nicely for reusing waste materials as well as creating something educational and representing an aspect of Thai culture."

Boosting circular economics globally

A series of interdisciplinary action research projects on creative waste innovation allowed Curie to test and iterate a range of process types and constructs. The journey into establishing further best practices and identifying the conditions to nurture more emergent circular economy activities across industry sectors and internationally will continue to expand.

A public report detailing the waste innovation projects, including the frameworks for systematic waste innovation developed through these projects, will be published this autumn.

Kanyaluck Muktana-a-nan from Remai team presented Ed-Kid, a DIY puzzle toy upcycled HDF waste.

Dr Curie Park

How sustainable are our online food shopping baskets?

E-commerce has completely changed the way we shop. Its value for consumers lies in its convenience, and for retailers in its new market potential and powerful sources of data. But how sustainable is it? This is a particularly pertinent question when it comes to food and fresh goods.

Dr Jag Srai, recently appointed as Co-Chair of Cambridge Global Food Security, has been researching these issues with his team in the IfM's Centre for International Manufacturing. We interviewed Jag to find out more about his work and the considerations for any of us when we click to buy groceries.

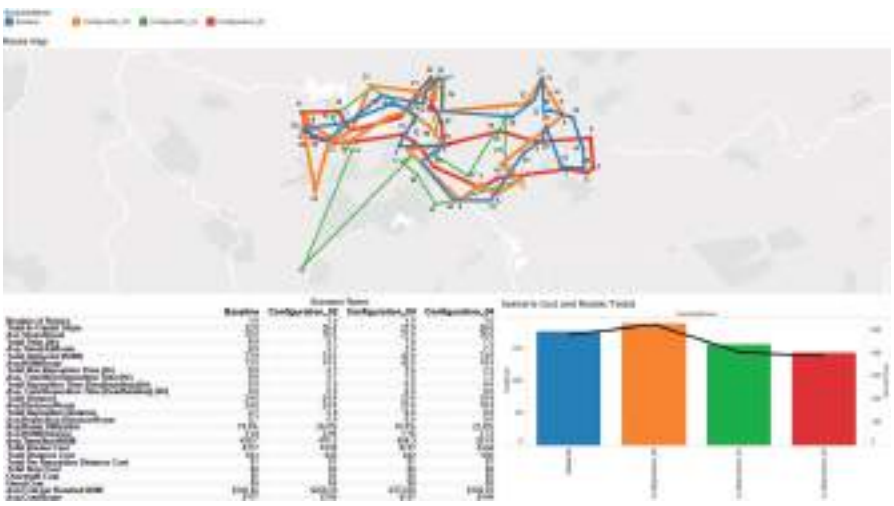
Jag, what issues do you see emerging from the transformation of the way we shop, including buying our groceries online?

The rapid growth of e-commerce has transformed our behaviour as consumers. In the UK, where e-commerce retail has led all other markets, 18% of consumer shopping baskets are ordered online and delivered directly to our doorsteps. It is anticipated that two-fifths of retail revenue will be online by 2040, with e-commerce becoming the dominant way to shop in major urban centres where market penetration of online shopping is higher.

As part of this transformation, there has been a drastic change in consumer expectations. Many of us as consumers have become accustomed to getting what we want, when we want it, with more choices around product format and delivery mode. In some instances, big retailers have moved towards same-day delivery, sometimes within 2-hour delivery windows in locations where population density makes this cost-effective.

Innovative retailers have developed powerful new ways to engage with consumers. A much more personalised form of interaction is now possible, with the ability to target customised offerings to individuals. For example, rather than a generalised special offer on a physical supermarket shelf, retailers can use data gathered on digital channels to target an individual online shopper with the type of special offer to which they are most likely to respond, on their favourite brand, timed to prompt purchase when they usually place a grocery order.

Despite these undoubted benefits of e-commerce in terms of consumer choice and convenience, there are also many challenges with this new paradigm. Do we need for example to guard against unchecked consumerism without regard for the environment, and to mitigate negative consequences for producers and for the regions from where products originate?



'Last Mile Modelling' solutions identify cost effective scenarios for delivery in target locations.

Figure reference: Srai, J.S., Settanni E. (2017), "Is last-mile delivery only viable in densely populated centres? A preliminary cost-to-serve simulation for online grocery in the UK". Proceedings of the 21st Cambridge International Manufacturing Symposium, 28-29 September 2017, Cambridge, UK

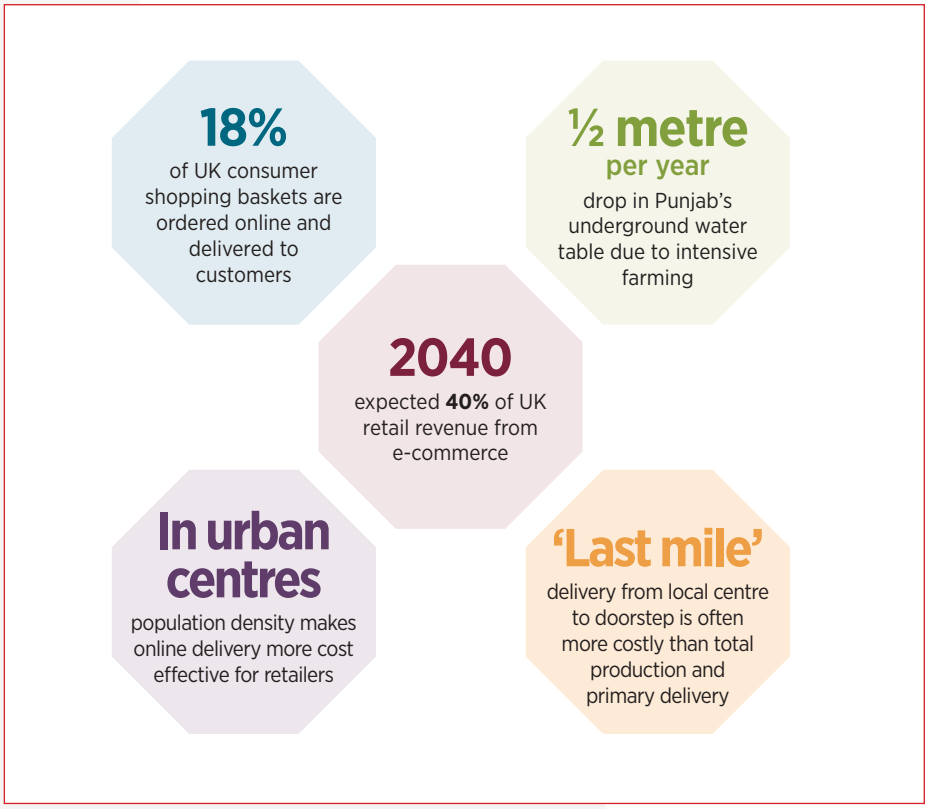
https://www.ifm.eng.cam.ac.uk/insights/global-supply-chains/cambridge-international-manufacturing-symposium/

Indeed, beyond the 'business case', there are many questions for retailers, producers and across the supply chain including issues of fair-value distribution, waste generated, resources consumed and sustainability of operations and how these might inform sourcing strategies. For the food industry there are of course some specific issues concerning timeliness of delivering fresh produce, and inventory management of products with expiry dates.

How do online food retailers currently decide what they can offer in terms of delivery options?

Any online retailer – however conventional or disruptive – has several strategic decisions to make: What are they going to compete on, and is this reflected in the trade-offs they make between delivery responsiveness, product variety, and convenience? Can they afford to offer delivery in less populated areas, or is it simply uneconomical to do so? How do they address the very real impact of short journeys on vehicle emissions and congestion, particularly in cities?

Our research team in the Centre for International Manufacturing (CIM) has been analysing what is termed the 'last-mile' of delivery. Analysis of cost data indicates that this very last section of delivery, reaching the door of the consumer from a local consolidation centre, can be higher than the total of production/assembly cost of the product and its primary shipment. The last-mile also creates a significant carbon footprint. We have been modelling optimum transport routes for delivery, using sales data provided by our industrial partners combined with publicly available data on population density for selected postcodes. This has enabled us to model cost-



efficiency for last-mile delivery, taking into account population density in e-commerce savvy areas, where online market penetration drives costs down. We are now extending this work to incorporate solutions that also consider the carbon footprint of delivery options to ensure the sustainability of this delivery model.

New approaches have been developed by an emerging breed of companies including Amazon, Ocado, Uber Eats and Deliveroo, demonstrating that tackling the last-mile logistics effectively in the e-commerce environment requires both new technology capabilities and new business models.

As consumers, when we order our groceries online, how can we know if we are making environmentally-responsible choices with our shopping baskets?

Not easily! Consumers and policymakers are seeking greater transparency and visibility on how our food is produced. In particular, there needs to be much clearer information on whether locations have been exploited for scarce resources, including something many of us take for granted, the sustainable use of water.

If we buy a breakfast cereal, for example, using crops grown in a water-challenged environment, that location has in effect exported its scarce resources to us. Water is used both in the production of the food, and also embodied in the product itself, which is being removed from that environment. The scenario that unfolds is that regions where water is scarce are often exporting that valuable resource to regions where there is not the same pressure on water; and this dynamic today is largely driven by financial economics rather than environmental concerns or in this case the water footprint.

There are also challenges in the supply chain around provenance and the traceability of food produce. As supply chains have become more internationalised, traceability has become more difficult. But there is growing public demand for evidence of where and how a product was made, whether it is safe to consume, and—increasingly—whether it was produced in a sustainable way.

What kinds of environmental and social stresses are being caused in regions of the world where products originate, including developing countries?

I visited the Punjab region in April as part of Tigr^{2}ess (Transforming India's Green Revolution by Research and Empowerment for Sustainable food Supplies) - a GCRF-funded £7.8 million programme, which is seeking to improve livelihoods and farming in India.
The Punjab is a region renowned for lush green fields, and known as the bread-basket of the Indian sub-continent, but is increasingly becoming water stressed. Data from the last decade confirms that the underground water table is dropping by half a metre per year in order to sustain the region's current food production role. So the much-heralded improvements in yield from cultivated crops comes at the expense of significant overuse of available resources. If this continues, one could project desertification of the landscape within a few decades.

There are social and political consequences too. Some five hundred farmers commit suicide every year in the Punjab (a region smaller than the UK) due to their inability to meet what they perceive as minimum income, despite the over-use of fertilisers, pesticides and water resources. So one of the objectives of the TIGR2ESS project is to support sustainable development through more informed resource and land use whilst also addressing the lot of the marginal farmer so that there are credible alternatives to the current situation of short-term resource depletion in order to generate income and pay debts.

So there's a requirement to bring together a multidisciplinary approach to address these issues – there are socio-economic aspects as well as the more familiar technology and operational interventions that support the building of scalable yet sustainable supply chains.

How optimistic are you about the prospects for making a meaningful difference through TIGR2ESS?

Our aim is to make a difference through local academic and institutional collaborations, and with specific technology interventions involving farmer-producer organisations, where resources are shared, know-how exchanged and new markets for non-commodity products developed at scale. The farmers are acutely aware of the unsustainable context they are in, and they are passionate about protecting their environment so we

have an engaged network of producers, technology developers and local institutions.

How does food waste relate to this pressure on global food supply?

Despite the pressure on food availability in many regions, simultaneously food waste is also a major problem. It can be difficult to assess the scale of food losses and waste, as many studies consider different elements of the farm-to-fork supply chain without necessarily considering agricultural process and avoidable storage losses, production and distribution inefficiencies, retailer write-offs and unused consumer produce.

However, the picture is far from uniform. In the developed world there is greater profligacy at the consumer end – as individual consumers throw a lot of food away uneaten. Whereas in other parts of the world, waste is more likely to happen further up the supply chain, with a complex set of causes including potential for crop failure, problems with moving crop from harvest to efficient distribution, absence of good warehousing and other transport and storage infrastructure.

How do you think technology can be used to address the issues around sustainability and food waste?

Working with our academic and industrial partners, we've been exploring waste within food supply chains. It's important to know where in the supply chain the waste is happening: what proportion of waste happens in agriculture, or post-harvest in manufacture, retail or in the hands of the consumer? Strategies to reduce waste can then be identified, and potential technology interventions to reduce loss or introduce re-use or recycling. With perishable goods, speed is of course a major concern.

CIM is currently participating in three projects funded by the European Institute of Innovation and Technology (EIT) exploring several themes around sustainable e-commerce supply, the traceability of organic food products, and the use of novel feedstocks. EIT Food was established as a £340 million programme in 2017 with the University of Cambridge as a founding partner, aiming to change the way we eat, grow and distribute food.

In one of these projects, Green Last Mile Delivery (GLAD), we've been exploring more sustainable ways for home delivery tailored to personalized nutritional needs. The project is looking at how online platforms may support personalised product choices and delivery options. When you buy a product, the data gathered about your preferences can help the retailer to target offers that are more customised to individual preferences. From a waste reduction perspective, presenting consumers with special offers on products as they approach expiry dates, or using 'nudge' tactics to influence consumers towards choosing more nutritional or sustainable options for their shopping baskets, is being explored leveraging latest technology developments in predictive analytics.

Digital platforms have the potential to provide new opportunities to connect consumers with their local retailers and farmers, offering personalisation, a more informed shopping basket and less waste. Consumers too are increasingly better informed and the transparency of sourcing policies and controls to demonstrate authenticity, quality and ethical sourcing practices is becoming part of the requirement of some e-commerce platforms.

Finally, as its new Co-Chair, how do you think Cambridge Global Food Security can help to support greater transparency and sustainability in food supply chains?

The issues we've been discussing here are complex and cut across many disciplines, and it is crucial that we bring together interdisciplinary thinking to address them.

Cambridge Global Food Security is one of the University's eight Interdisciplinary Research Centres (along with Cancer, Conservation, Energy, Infectious Diseases, Language Sciences, Neuroscience and Stem Cells), which are established as cross-School initiatives to tackle interdisciplinary challenges. It has evolved from a Strategic Research Initiative, and now involves around 160 researchers from 24 departments, pulling together research and expertise including crop science, policy, economics, public health, development studies and engineering.

Our role is to use our interdisciplinary research to develop innovative solutions and provide robust evidence to inform the decisions of industry, policy-makers and the public, so that we can address the challenges of feeding a growing world population in a sustainable manner.

For further discussion please contact Dr Jag Srai, jss46@cam.ac.uk

To find out about the Cambridge Annual International Manufacturing Symposium, 26-27th September 2019, Cambridge, UK, please visit: cimsymposium.eng.cam.ac.uk

Dr Jag Srai

Scalable customisation:

Developing technologies for higher volume, lower cost customised products

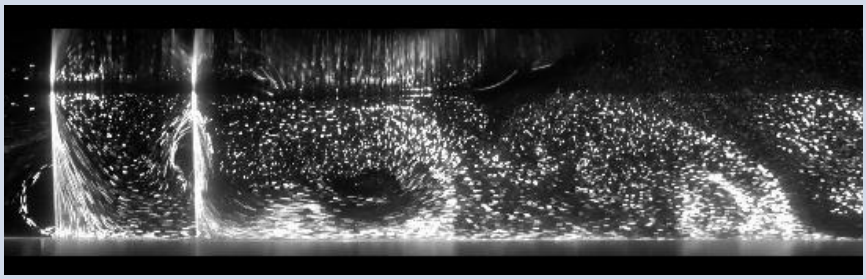
How can manufacturers develop sophisticated customisable products at scale, which are affordable both for the manufacturer and for the consumer? Customisation is no longer the exclusive domain of the wealthiest: the demand from mass markets, both business and consumer, is for increased ability to personalise products. Manufacturers are seeking ways to deliver this customisation in higher volumes at lower unit cost.

Dr Ronan Daly and Dr Cristina Rodriguez-Rivero from the Institute for Manufacturing, University of Cambridge, provide an insight into an example of late-stage customisation, through their research group's collaborative project with multinational glass manufacturer Pilkington (NSG).

Innovative manufacturers are pursuing approaches for making customisation more affordable, responding to market opportunities to address increasing consumer demand for personalised products. The prize is to gain competitive advantage and customer loyalty by delivering customers with the specifications of their choice whilst keeping the costs of production low.

Moves towards "mass customisation" can be supported by emerging technologies which enable product features to be added to order at a late stage in the manufacturing process.

New applications of advanced inkjet printing technology provide one such example. Our Fluids in Advanced Manufacturing research group at the Institute for Manufacturing has been working with glass manufacturer Pilkington (NSG), exploring technologies for printing customised embedded electronics, sensors and other features onto curved glass surfaces at scale. This is a technically challenging process, but offers tantalising potential: rather than embedding the electronics into the glass earlier in production, the use of inkjet printing technology allows late-stage customisation to order. We are investigating how the capabilities offered by inkjet can be scaled up for customisation that is affordable both for the manufacturer and the customer.



Understanding airflows

There is a strong link between misplacement of ink droplets and the surrounding airflows. We are working to understand this better, in order to improve the ability to deliver sensors, responsive surfaces and electrical pathways to non-flat surfaces. To do this, we apply advanced visualisation techniques to study droplets and airflows in commercial and in-house equipment to analyse the effect of a variety of printing parameters.

Dr Cristina Rodriguez Rivero joined IfM in 2014 as a Research Associate and is focused on droplet and jet behaviour, inkjet visualization techniques, aerodynamic effects and complex fluid behaviour in the micro- and milli-scales.

Customising curved glass

Large curved glass products are used in many different types of product. In certain applications, such as automotive glass products – mainly windscreen, windows and mirrors – production involves a range of multiple-layer processing steps before the glass is formed into curved shapes. The current manufacturing of float glass and advanced coatings is only efficient with continuous production, but can make customisation difficult and costly if it happens early in the production process.

Pilkington's R&D team has identified that inkjet printing can enable customisation at a later stage in the process. A range of product features (including embedded sensors and security features) can be added using inkjet, through advanced functional material deposition directly to product surfaces.

A particular challenge is to identify new techniques for printing directly onto larger curved surfaces. Existing technologies for achieving this have limitations: these include continuous inkjet printing (CIJ) which is used for printing barcodes and best before dates to items like small bottles, but this can be limited in terms of achievable colour and precision over larger surfaces. Drop-on-demand (DoD) printing has recently seen a renewed interest in printing to complex shapes but will face severe challenges in terms of precision and predictable drop placement when working on non-flat surfaces.

With this process, airflows can have a significant impact on accuracy, causing misplacement of ink droplets. Our research team at the Institute for Manufacturing has been working to characterise the influence of surface texture and curvature over aerodynamics of inkjet printing.

One of the other technical issues with printing on to large or complex surfaces is that the printhead itself needs to be moved across the product. This is different from the existing solutions where the product is the moving element, using automation to enable simple, smaller curved surfaces to move past the inkjet printhead.

To develop an improved understanding of printing direct-to-shape, we are working with Pilkington to map the detailed surface textures and chemistries that will need to be coated. We can then examine with ultra-high speed imaging the surface impact and drying dynamics of advanced functional material inks.

We are developing a virtual simulation of product printing, which helps us to determine the influence of factors that can affect the precision of the process, including angle of approach, rate of printhead rotation and required distances. Pilot trials are planned for testing different product requirements.

The collaboration is enabling the necessary early research to guide an exciting, ambitious and long-term research agenda focused on inkjet printing to create active devices and conductive tracks on advanced curved glass products.

Scaling-up customisation

It is one thing to establish new techniques in the lab, and quite another to scale them up for a manufacturing environment and for higher volume production. We focus on this need to understand scaling up, and collaborating with manufacturers including Pilkington provides a way to test and analyse lab-based results in a production environment. Issues such as the impact of airflows on inkjet accuracy need to be understood both in the lab and in the factory for development of technologies which are both cutting edge and robust.

We anticipate that establishing and refining production techniques using advanced inkjet printing to be reliable in a factory environment will enable manufacturers to unlock affordable customisation in higher volume.

Nurturing innovation

Pilkington has a dedicated R&D facility at its European Technical Centre in Lathom, Lancashire, where technicians have the freedom to test new ideas and look ahead to the next big trends that will shape the future of glass. Known as the Pilkington Innovation Incubator, the facility is a base where Pilkington's staff can collaborate with any partner – from new tech start-ups, to larger businesses in other industries, to universities – in the pursuit of technological breakthroughs.

Dr Su Varma, Incubation Portfolio Manager R&D, has been at the forefront of building and growing the Innovation Incubator at Lathom. He explains: "The incubator is designed to look further into the future – at what the medium and long term needs of the company may be in terms of technologies, and how these could give rise to new value-added products that take us into new markets. It's about asking 'Where are the opportunities in the future?' Clearly, they tend to be outside of our normal glass world, which is why we link up with start-ups and other companies and Universities including Cambridge to find those early-stage innovations that we should be thinking about. Our collaboration with Ronan Daly's centre at the Institute for Manufacturing, University of Cambridge, has directly helped us to explore cutting edge applications of inkjet technologies.

"Once we have set up a project through the incubator we will work to short timescales whereby we run the project for three months before inviting commercial colleagues to review it. If the commercial team believes there is a new, viable product in the offing, we will move it from the incubator into our normal, rigorous product development processes. We then fill the funnel mouth of the incubator with other new things and carry on."

Dr Ronan Daly

Dr Cristina Rodriguez-Rivero

Transforming innovation in rail

The UK rail industry is ripe for innovation. Challenges and frustrations faced by passengers are frequently hitting the headlines. But where should the industry start with making innovations to improve the customer experience? And how can it make sure customers are listened to as part of managing the innovation process?

Rob Munro, IfM Industrial Associate shares some insights into AIR4, a government-funded initiative to bring a more structured approach to making innovation happen in the rail sector.

If passengers could decide how to improve their rail journeys, or their experience at train stations, what would they prioritise? When you take a train, what would make the most difference to you and your fellow passengers on your journey?

As part of a national initiative to stimulate innovation in the rail sector, customer input and feedback has actively been sought, alongside expertise from the many organisations involved in the rail service ecosystem.

At London Bridge Station (itself having been through a recent major redevelopment) an 'Innovation Hub' has been installed, providing a space where passengers can find out more about new concepts currently under consideration for improving rail services, and share their feedback and insights. Using touch screens and smartphones, members of the public are actively encouraged to give their input. The Hub is staffed by project partners and suppliers, adding valuable personal interactions as another way to prompt exchange of ideas.

Taking a structured approach to managing innovation

The Innovation Hub is part of Advancing Innovation in Rail 4 (AIR4), an Innovate UK-funded initiative, which builds on work done previously under AIR3 to develop a passenger-facing IT infrastructure. The objective of AIR4 is to identify a range of digital innovation tools, platforms and assets that the wider supply chain and passengers can engage with and use, with a focus on passenger experience at stations.

Over the past decade, the UK rail industry has undergone significant growth in passenger numbers and increased investment in infrastructure. But with the higher demand, the quality of passenger experience has struggled to keep up.

This presents a pressing need to identify innovations which can bring dramatic improvement to the customer experience. But crucially, these innovations must be managed and planned strategically, by focusing on customer-centric priorities, and by creating a roadmap for development and implementation.

But taking a structured approach to managing innovation is not easy, particularly in a traditional sector like rail with legacy standards and ways of working. The fragmented nature of the UK rail industry—encompassing train operators, constructors, rail operators, suppliers, station operators and passenger bodies—can hinder the pace and scale of

The Innovation Hub at London Bridge Station

innovation. So industry-wide collaboration is essential to deliver improvements successfully. This requires involving a broad range of passenger-facing organisations (PFOs) and the supply chain – any organisation that has products or services that impact on passengers.

Bringing these parties together, the Institute for Manufacturing has facilitated a series of workshops with stakeholders across the rail industry to clarify the challenges for passengers, identify key innovation themes and hot topics, and develop a strategic technology roadmap focused on bringing improvements to large mainline stations in the UK.

For the rail industry, the whole process was itself an innovation. Starting out, it wasn't clear what the end output would look like, and the process was refined as the project progressed.

The innovation funnel

An initial workshop with 50 people from across the industry kicked off the project with an exploration of the passenger experience. This identified 20 themes for improvement where innovations could be focused, including areas such as sustainable rail infrastructure, ticketless travel, station platform upgrades, and smart techniques to manage passenger flows.
Using data-driven decision making and established IfM frameworks for supporting the selection process, six themes were chosen for further development in a second workshop. Each was assigned a theme leader, and a team of 3 or 4 people who focused on creating an innovation under this theme during and between workshops.

In the final workshops, the teams produced specific concepts for real potential innovations based on the six themes. These were presented to a portfolio steering group led by project-partner Costain, to decide which of the six ideas would go forward for development.

From ideas to reality

To implement these ideas and take them through to commercialisation, high level strategic roadmaps have been produced with a focus on a longer timeframe, as well as more granular innovation roadmaps to apply to specific and tangible improvements currently being worked on.

An IT innovation infrastructure is used to scale and expand the initial part of the innovation funnel through into development and commercialisation, including creation of "open" digital assets which are being made freely available to the rail industry as a way to stimulate collaborative innovation at a faster pace. All ecosystem partners are being encouraged both to access and to contribute to the digital assets.

Listening to customers

So in the midst of this complex process, involving many different organisations and innovations, and taking place over a long-term period, how can the AIR4 project partners ensure that the customer voice is still heard loudly and clearly?

AIR4's aim is to drive a customer-centric approach: listening to customer opinions and ideas and building innovations which are focused on improving the customer experience.

This involves providing a chance for customers to share their views and to get involved in testing innovations. Often finding ways to do this requires innovative thinking of its own. The Innovation Hub at London Bridge Station is one such example – by physically locating a means for gaining customer input visibly in place where customers are passing through, and by talking with them during their journey when their rail experience is fresh in the mind, AIR4 are gaining immediate and engaged interactions.

There are many possibilities that physical spaces like the London Bridge Station Innovation Hub can offer, including harnessing technologies such as virtual reality (VR) for gaining feedback. VR is increasingly being used in construction and manufacturing to test new designs, structures or other innovations, and can be a valuable way to trial new concepts through immersive experiences.

Such spaces are also an important channel for customer service, promoting better communication with customers and a more inclusive relationship between customers and the range of suppliers they interact with during a transaction.

AIR4 have used other means for gathering customer feedback too, including online tools such as the open innovation portal to provide an interactive means to facilitate dialogue.

Often the best ideas come from the people who need to use them. In the rail sector, a cultural change to place passenger experience at the centre of change will be fundamental to delivering innovation successfully.

AIR4 draws on cross-discipline skills and experience from its project partners, Costain, IBM, Milne Research and the Institute for Manufacturing. The aim is to deliver a scalable digital innovation infrastructure to help make the UK rail industry among the best in the world.

Rob Munro

From innovative ideas to viable businesses: How an IP strategy can help

Intellectual property (IP) is a major asset for most companies, from entrepreneurial ventures through to multinationals. It is key for capturing the value of innovation, and a good IP strategy needs to be tied to—and will help deliver—business objectives.

Looking at how start-ups can develop their IP strategy provides a window into this subject for any type of organisation. Dr Frank Tietze and Tianyi Wang of the IfM's Innovation & Intellectual Property Management research group explain how they have been working to identify new ways of supporting start-ups, as well as bigger companies, to develop an IP strategy that works for them.

The challenges of IP

Brilliant ideas are the foundation stones of entrepreneurial ventures. IP strategy is of particular importance to new technology companies and to entrepreneurs with ambitious plans for growth.
So how can start-ups use IP to maximize the value captured from their innovations?

There are some significant hurdles for start-ups when it comes to strategising their IP. New companies typically lack the resources – both in terms of finance and experience – to develop their IP strategies. Unfortunately, it can also be difficult to find truly independent advice. While there are plenty of patent attorneys, they have an interest in selling patents or trademark applications, and often their incentives are not well aligned with the needs of start-ups.

There is commonly a sense of urgency in start-ups to get patents in place as soon as possible. However, moving fast isn't always the best way – it's more important to consider and time the sequence of activities carefully. For instance, technical inventions can be kept as a trade secret before the product launch and can then be converted into patents.

Timing is also important for managing the costs of IP. While filing a first patent application isn't usually expensive, translating technical patent documents into multiple languages (such as Chinese, Korean or Portuguese) for filing subsequent national designations can become costly.

Typically, once a start-up's patent family is in place for its core technology, the emphasis is then likely to change towards the use of this IP, possibly with external parties (for example in the form of out-licensing). Additionally, trademarks typically become important closer to product launch.

A coherent IP strategy considers the sequencing of important IP-related activities and how to best align those with the business objectives. Having such an IP strategy in place can then be very valuable: for instance when pitching to venture capitalists: demonstrating how the start-up will harness IP strategically will help them to build confidence with VCs by conveying depth of business acumen.

Developing an IP strategy

Over the past years, we have been working with start-ups and larger companies to help them develop viable IP strategies that align with their business objectives. Our research has identified common challenges and issues, and looked at how tried-and-tested frameworks for creating strategic roadmaps can be adapted to help navigate some of the challenges,

then used to build IP strategies to meet each company's unique business needs. Central to our approach is the process of transferring capability to the firm, equipping them to continue developing and refining their IP strategy in-house.

IP strategy roadmaps are developed using a workshop approach, which brings together key people across an organisation. A key advantage of roadmaps is the prominence of the timing dimension, which is helpful for companies to think about when is the best time to implement certain IP mechanisms and in which sequence.

Four stages for devising IP strategies

There are four stages of strategic thinking that start-ups work through with the IP roadmapping process, following an emergent strategy development process.

- The **first stage** involves exploring the company's business model, technology strategy and objectives. This can be done, for instance, with a topic-roadmapping approach.
- In the **second stage**, we identify those business objectives that can actually be supported by IP. For example, avoiding competition after product launch or collaborating with an external player to help jointly develop a product or service.
- The **third stage** involves the identification of specific IP assets that are relevant to achieve each of the business objectives identified.
- In the **fourth stage**, specific IP-related actions are identified along the roadmap's timescale. We ask what particular actions need to be undertaken, and when, in order to gain the most from those IP assets identified in the previous step.

Perspective from a growing company: securing your opportunity through aligned strategy

Rob Mann from PragmatIC, a company which produces ultra low-cost flexible integrated circuits (FlexICs) that can be embedded into everyday objects, explains why developing IP strategy is so crucial:

> "IP for young companies is particularly important because it helps them establish a position in the market. These companies also need to account for the other IP already in existence, and understand how to work with or around it.

"If you've come up with something innovative – a new product or a creative way to do something, or a way to fill a gap in the market – you need to check that you can secure that market gap. This could include things like URLs, domain names, and designs. And once that new idea becomes successful and interesting to people, then IP is important because it prevents people copying you or diminishing the strength of your opportunity.

"It can be difficult to navigate the technical language and legal frameworks of IP, with concepts that entrepreneurs may be unfamiliar with. There's a lot to take in, and huge volumes of information that may be relevant. Someone else may also be in the process of trying to protect IP in the same area. Entrepreneurs may have a strong sense of direction for their company, but things don't always go to plan.

"It may sound obvious, but IP should flow from organisational strategy – this is the case for all kinds of organisations. Roadmapping is an efficient way to derive IP strategy from the needs of the business, and to ensure the two are aligned."

In an effort to equip entrepreneurs with the tools they need for IP strategy development, we are planning to make our material available online free, including a guidebook for the process and moderator slide-sets to run an IP roadmapping workshop. The hope is that the material can enable start-ups to conduct an IP strategy exercise themselves, but also that this openly accessible material will be picked up by entrepreneurship teaching programmes. In those programmes, IP is often emphasized as important, but often not in much detail, so our toolkit can be used to add extra depth. We hope that by spreading good practice on IP strategy development, and helping start-ups to overcome some of the obstacles, we'll be able to help companies to maximize value from their IP.

Dr Frank Tietze

Tianyi Wang

Martlet 3

Student insights

IfM students help to build the UK's largest-ever nitrous hybrid rocket engine

The IfM's undergraduate teaching emphasises practical application, and encourages students to develop their designing, building and testing skills. Two of our undergraduates have been part of a small team of students from the Engineering department who have produced the largest impulse of any nitrous hybrid rocket ever fired in the UK.

The 'Pulsar' engine was designed and constructed from scratch by Cambridge University Spaceflight (CUSF) students over an 18 month period. It was tested and successfully completed its first static firing in January 2019 at Airborne Engineering Ltd's test facility in Westcott, Aylesbury.

CUSF's Matt Escott, a student at IfM, explained:
"Pulsar will be the engine that powers the Martlet 4 rocket, which CUSF is planning to launch in 2020. The engine is more powerful than anything made by amateurs before. Our aim with Martlet 4 is to break the UK amateur-built altitude record. The current record is 10.3km and Martlet 4 is designed to exceed 15km."

Pulsar burns nitrous oxide combined with high density polyethylene fuel to produce thrust for a total of 36 seconds. Over the course of the static firing test, the engine produced a measured impulse of 53,855 Newton seconds.

Airborne Engineering has been an enthusiastic supporter of CUSF. It employs six people at the facility, four of whom are ex-Spaceflight themselves. "We needed to use Airborne's test facility including the concrete bunker," said Matt. "Pulsar's hybrid fuelling means the solid fuel is stable until we add the liquid nitrous oxide just before ignition."

The Pulsar project follows the launch of CUSF's Martlet 3 rocket in Nevada in 2017. Martlet 3 reached a max velocity of Mach 1.2, but the commercial off-the-shelf rocket motor exploded in flight.
Matt explained: "The first stage of Martlet 3 was destroyed in the explosion, but the dart was able to ride the shockwave of the blast and fly in a stable trajectory to 3.5km. Our avionics went beyond the call of duty, surviving the explosion, and the dart maintained live telemetry throughout the flight and correctly deployed parachutes for a safe recovery. The experience with Martlet 3 definitely motivated us to try and build something better!"

To fund the project, CUSF pitched through a Dragon's Den-style pitching presentation to the Engineering Department's Student-led Projects and Industry Partnership (SPIP) programme. This has industrial support from Boeing, BP, Jaguar Land Rover, National Instruments and Marshall Group through sponsoring, mentoring and technical advice.

"The project has been exciting to work on," said Matt. "Beyond wanting to get Martlet 4 higher than any other amateur rocket, we're also interested in the research potential and the practical aspects of building and testing it, including applying things we've learnt in the Engineering course."

Further information: http://bit.ly/2FINyki
Watch the PULSAR Hybrid Rocket Test video here: bit.ly/2OzSevQ

STIM Consortium

The Strategic Technology & Innovation Management (STIM) Consortium is a practice-oriented research and networking collaboration between industrial member companies and the Centre for Technology Management.

We are launching the next year's annual programme on 21st November 2019. If you are interested in attending this event, or finding out more about joining the STIM Consortium, please contact Dr Robert Phaal rp108@cam.ac.uk or visit www.ifm.eng.cam.ac.uk/research/ctm/stim.

Members of the Consortium benefit from:

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- The opportunity to influence the direction of research and development, with the associated early benefits gained through participation in case studies and application pilots.
- Transfer and application of methods developed, enabled by guidance notes and training packages.

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- **The Cambridge Tribology Course: Friction, Wear and Lubrication 2019**
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  Intensive three-day programme offering an excellent opportunity to gain an overview of the field of tribology.

- **Strategic Roadmapping**
  9 – 10 October 2019

  A thorough introduction to strategic roadmapping, guiding participants through each step of the roadmapping process.

- **Visual Communication**
  6 November 2019

  This course outlines the fundamental principles of designing visualisations and provides practical guidance on how to apply them in a business/ management context.

- **Cambridge International Manufacturing Symposium 2019**
  26 – 27 September 2019

  The annual Symposium this year focuses on shaping the future of global manufacturing supply networks, and how sustainable value can be delivered through digital platforms.

- **Cambridge Service Alliance Industry Day Conference**
  16 October 2019

  This one day conference will provide unique insights from leading service providers and offers a valuable opportunity to hear and discuss the latest developments in service thinking.

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