Design Engineering and Advanced Manufacturing

UK manufacturing employs 3.6 million people, accounts for some 17% of national GDP, and contributes half of all UK exports, but when financial, supply-chain and manufacturing-related services are taken into account, many more UK jobs depend on it. However, the manufacturing sector in the UK continues to face relentless competitive pressures from around the globe, particularly now from the emerging economies of India and China.

UK CAPABILITY

Notwithstanding these pressures, the UK retains areas of global excellence, such as aerospace, speciality chemicals, pharmaceuticals, food processing, high performance cars, and advanced/nano materials. In addition, the UK has many successes in prestigious design-led construction projects, and key UK strengths in this sector include problem solving in harsh environmental conditions and for iconic design.

The UK capability is based on strong traditions of excellence in design and manufacturing among our leading companies, high quality research in engineering, biosciences and ICT and a flexible and innovative approach to business problems. The Innovative Manufacturing Research Centres and Grand Challenges, established by the Engineering and Physical Sciences Research Council, represent a significant research resource for UK businesses which have an interest in the latest developments.

The best companies in the UK are recognised by competitors to be among the best in the world but there is, of course, a range of capability. The Manufacturing Advisory Service (MAS) is helping to address this through assisting companies to improve their business processes.

GLOBAL MARKET OPPORTUNITY

Competition from emerging economies and the speed/reduced cost of communications has moved manufacturing to a system of global supply chains and much greater specialisation of activities between countries. This, together with shortening life-cycles and time-to-market for products and services, increased environmental pressures and sustainability issues, are the key drivers of change facing UK manufacturers. They also present market opportunities for those firms which adapt to the new situation.

These opportunities lie, not only in the markets of the developed world, but increasingly in the developing world where growing affluence and demands for a modern infrastructure are resulting in increasing demand for quality products based on innovative design, high functionality and precision manufacture – areas of UK strength.

PRIORITIES FOR ACTION

Taking account of a range of Innovation and Growth Team (IGT) reports, national strategies, such as the National Aerospace Technology Strategy, and the major European initiative in this area (Manufuture) together with the feedback from workshops which have been held to discuss this topic, we consider the priorities for action to be as follows:

New business models for enterprises:

- Lean manufacturing and processes (resource efficient, low cost, sustainable manufacturing processes)
- Digital manufacturing businesses (including collaborative environments, networked business, through-life services)

Design, simulation and modelling, validation and advanced engineering research; priorities include:

- Design for reliability, availability and maintainability, through-life support, health management and prognostics
- Design, simulation and modelling of advanced structures
- Validation including non-destructive testing

Advanced manufacturing technologies and processes priorities include:

- Advanced forming and assembling tools and techniques (including robotics and flexible automation)
- Advanced manufacturing technologies for micro- and nano-systems
- Advanced instrumentation and control/use of radio frequency ID

In taking forward these themes we shall wish to develop real applications among our high value industries and to consider the wider barriers to rapid uptake in a holistic manner. This will include a review of metrology needs and standards requirements in these priority areas, as well as working with the Global Watch Service to help businesses appreciate the speed of developments overseas and to identify opportunities to collaborate with centres of excellence around the world, and ensuring that UK organisations can capitalise on European programmes in these areas.

An important priority will be to develop a community of interest around these challenging issues and technologies, building on the capability which lies in the Innovative Manufacturing Research Centres with the further objective of providing the Manufacturing Advisory Service with a continual flow of information and experience around excellence in design and manufacture.

PURPOSE OF THE PAPER

The purpose of this paper is to identify and prioritise the key technologies over the next three to five years in the area of Design, Engineering research and Advanced Manufacturing (DEAM). The initial methodology brings together information from existing sources, in particular the recommendations contained in the relevant Innovation and Growth Teams (IGT) and related UK studies, European reports, and consultations with the research and business communities, as a basis for the selection using criteria developed by the Technology Strategy Board (TSB).

Introduction

Importance of manufacturing to the economy

Design, engineering research and advanced manufacturing underpins much of the European and UK economies. For example, of the 26 million businesses in the European Union (EU) about 2.5 million (10%) are manufacturing based; over 99% are SMEs. EU manufacturing business employs over 36 million people and contributes approximately 22% to total EU GDP. European manufacturing features strongly in international trade with an 18% share in 2002, compared with 12% for the USA and 8% for Japan. In certain sectors, notably automobiles, mechanical engineering mobile communications equipment and (recently) civil aviation, Europe producers now have a leading position.

The UK scene is similar. UK manufacturing accounts for some 17% of national GDP, employs 3.6 million people and contributes half of all UK exports. However, these figures understate the contribution of manufacturing to the economy because manufacturing now buys-in many of the 'business services' which were once in-house. Estimates suggest that as much as 75% of the EU GDP and 70% of employment in Europe may depend on manufacturing as a result of the financial, supply-chain and manufacturing-related services. The above may underestimate the UK position in particular since the UK has outsourced more thoroughly than comparable European economies.

In other words, a significant reduction in manufacturing capacity in the UK and Europe would have a significantly negative effect on the overall GDP and its sustainability. To quote from the EC report 'MANUFUTURE – A Vision for 2020', 'an economy based on service industries alone will not survive in the longer term.' Europe would become economically less successful and its people poorer without a strong manufacturing sector linked with its associated service businesses.

Trends in EU and UK manufacturing

The manufacturing sector has faced severe and relentless competitive pressures for the past 50 years, from Europe and Japan, the 'Asian Tigers' and now from the emerging economies of India and China. Some sectors of UK manufacturing have almost disappeared, others have outsourced much of their manufacturing operations to low cost countries while retaining only a few key operations in the UK, and others have sought to move up-market into higher value-added, more knowledge-intensive goods. Despite these pressures manufacturing turnover has continued to grow and numbers employed to fall.

Competition from emerging countries is just one of several key drivers of change facing manufacturers now and probably in the longer term; others which demand attention would include:

- Ever shortening life-cycles and time-to-market for technologies, products and services.
- Environmental and sustainability issues including recycling, waste and energy minimisation.
- The trend towards greater functionality and miniaturisation which is exemplified by the growth in micro and nano technologies.

Given these various drivers for change and economic importance, the future of manufacturing has formed the subject of many 'foresight studies' and similar strategic reports from expert groups including the Foresight Manufacturing 2020 (of 2000), the European Community-funded MANVIS (Manufacturing Visions) pan-European Delphi-type study (of 2003),and the FuTMaN scenario-based analysis of future European technologies. The ManuFuture European Technology Platform (ETP), made up of many of European leading companies, has recognised that the present industrial paradigm of trying to compete by reducing costs is unsustainable; Europe's traditional industries cannot hope to compete on price with the standardised products against low wage SE Asian countries and

even Europe's hi-tech sectors must seek new innovative strategies to survive against the rapidly-developing economies Taiwan, Korean and, of late, China and India. The ManuFuture ETP argues that European manufacturing can only compete with high value-added products based on:

- new business models and strategies; innovative value-added products and related services;
- leading-edge industrial manufacturing technologies
- rapid exploitation of emerging manufacturing science and technologies;
- greater synergy between education and academic R&D and manufacturing.

Impact of information and communications technologies

Probably the largest impact on manufacturing has come about from the widespread application of information and communications technology (ICT) although even here, despite the competitive pressures, Europe including the UK have performed less well than the comparable US economy. According to recent studies, more than half of the productivity[1] gains in our economies today are attributed to ICT[2,3]. In the EU for instance, of around 1.4% productivity pa growth between 1995 and 2000, 0.7% pa was due to ICT. Other evidence suggests that Europe's productivity gap with the US is to a large extent explained by its weaker investment in ICT. The gains stem both from the production of innovative high value ICT-based goods and services as well as from improvements in business processes through the wider diffusion, adoption and use of ICT across the economy. Both regions had used ICT to increase their operational efficiency but the studies have indicated that Europe has invested less (18% of total investment) and benefited disproportionately less (by 29% productivity growth) than has the USA which had spent 42% of total investment in ICT and gained 80% in productivity.

UK Government assistance to the manufacturing sector

The government attaches considerable importance to the manufacturing sector for the reasons outlined above. In 2002 DTI published the Manufacturing Strategy which set out the seven 'pillars' necessary to help build a successful knowledge-intensive manufacturing sector. Amongst the priorities for action the government established the Manufacturing Advisory Service (MAS) delivered on a regional basis aimed at raising productivity and competitiveness through best practice methods. Two years later (2004) DTI reviewed the strategy and its priorities and established the Manufacturing Forum to implement the priorities including 'promoting science and innovation' and 'high skill, high performance workplaces'. MAS has proved itself particularly successful by generating £188 million in added value through assisting companies in their normal business activities, in particular through the application of lean manufacturing techniques to the production processes.

Trends in R&D and innovation

Manufacturing sectors perform around 75% of all UK R&D and contain many of the UK's top companies such as BAE Systems, Ford, Unilever, Airbus and Rolls-Royce. The entire sector shows a tremendous scope for innovation-driven growth both from a greater use of ICT to manage its business, production and service-related processes and in the development of new technologies and manufacturing processes. Total R&D shows a general upward trend albeit a slow one.

Coverage and key UK sectors

The technologies to be included under the design engineering and advanced manufacturing theme should ideally find applications across much of the Manufacturing (section D of the 2003 Standard Industrial classification), parts of Construction including constructional materials (parts of sections CB – 14.1, 14.2 and F – notably 45.2), and Business Activities (parts of sections K – principally 72, 73). Within this huge area, certain industrial sectors stand out as key in terms of their contributions to UK economy (current or with potential for growth), viz:

– Aerospace: this is a global industry in which the UK is a leading player. UK industry has ~13% share of the global market (second only to the US), with turnover in the UK of ~£17 billion and employing 120,000 directly in over 3,000 companies. The gross added value (GVA) of the sector was estimated to be £6.7 billion in 2000. It is the second most research intensive sector in the UK (after pharmaceuticals). Drivers specific to this sector include commercial pressures to reduce fuel consumption and

regulations for lower noise, emissions and greater safety. The latter in particular means technology can take up to 15 years to progress from basic science to product application. The UK has a strong academic research base with world leading expertise in several key areas.

– Automotive: the UK is Europe's most diverse and productive vehicle manufacturing location and a global centre of excellence for engine development and production. The sector shows a GVA of >£8 billion from a turnover of >£45 billion and makes a near 10% contribution to UK export of goods. The UK is currently a favoured location for inward investment. In addition to volume and niche vehicle manufacturers and their supply chains, it hosts a strong design engineering support infrastructure. The UK is well placed to provide the key technologies required by the sector including highly developed capability in power-train and combustion research. Drivers specific to the sector include tightening emission controls, transport initiatives such as road charging and voluntary codes on CO_2 reduction.

– Modern built environment (MBE): this is one of the fastest growing sectors in the UK (approximately 12% of total UK GVA) and the UK stock of buildings and works represents nearly three quarters of the national capital stock. Professional services developed here can be developed further and the UK has many successes in prestigious design-led projects. Key strengths include problem solving in difficult ground and climatic conditions and iconic design. Much of the significant added value from this sector comes from architectural and engineering design with a key future driver being that of sustainability. The UK has considerable research strength, in more than 30 universities, in the industry itself and in Research and Technology Organisations (RTOs).

– Chemicals and chemical engineering technologies: the chemicals sector underpins much of the UK manufacturing base. Products of the chemical industry are the basis for a wide range of manufacturing activity, including pharmaceuticals, plastics, water treatment materials, man-made fabrics, detergents, disinfectants, cosmetics and paints. The industry employs around 230,000 skilled individuals across the UK and accounts for 2% of GDP and 10% of the manufacturing industry's GVA. Around £2 billion is invested annually, which represents 14% of total manufacturing investment and a further £3.5 billion is spent on R&D. The industry is also the UK's top manufacturing export earner with overseas sales of around £29 billion.

– Food and food processing: in Europe, the agro-food industry has the leading position amongst all sectors with a turnover of over €810 billion (~£570 billion) in 2004, exports of €40 billion (2003) and a workforce of 16 million. The UK industry is comparatively smaller but nonetheless still makes up around 8% of UK GDP and nearly £74 billion of GVA. In 2003, UK consumers spent about £150 billion on food, drink and catering services. The UK food industry employs about 3.8 million people and exports almost £10 billion of food and drink products, over 90% of which have involved some manufacturing process. Consumer demand, changing lifestyles and anxieties (convenience, health, regulation and safety) determines innovation in the sector, with globalisation an increasing force as producers must compete on novelty, quality and lifestyle products rather than cost alone. R&D spend by the food industry of about £80 million is small compared with its overall size. Although a few large companies have research facilities many business rely on the three RTOs and government-funded institutes. Research Councils (Biology and Biological Sciences Research Council and the Engineering and Physical Sciences Research Council (EPSRC)) and the Department for the Environment, Food and Rural Affairs (Defra) support the underpinning basic research.

Scope and coverage of R&D spectrum

The scope for research will cover the entire spectrum between 'basic research' and 'experimental development', and provides support for collaborations between the science base and business as well as between business organisations themselves.

As many of the medium term priorities for DEAM are likely to be informed by existing sector specific technology roadmaps and the current state-of-the-art research with respect to dependent technologies, emerging concepts (e.g. nanostructures or biomimetics) and their use within DEAM should merit consideration for support.

The scope of the research agenda mirrors the sectoral coverage. Key parts of the UK transport system will probably benefit from R&D in this area, such as rail, marine and freight sectors. The focus of much of the research relevant to the design and manufacture in the chemicals and related process industries may overlap with other pillars as shown in Figure 1, although the key driver for these will be covered by the 'sustainability' theme.

The EPSRC sponsors 18 Innovative Manufacturing Research Centres (IMRCs) and 'Grand Challenges' (GCs) with an applications focus and capabilities which could contribute to the research agendas of many of the sectors included above, directly or indirectly. These IMRC/GCs already have close ties with their business sectors through sponsor and management boards with a substantial presence of industry representatives.

Technologies coverage of key UK sectors

The DEAM pillar should also take an inclusive approach to technologies, as appropriate to its coverage of the several large and diverse sectors of the economy as described above. Information and communications technologies (ICT) forms the basis of most design and production businesses, both as the platform for design, simulation, modelling and validation software and to manage the normal business operations of the organisation. Engineering research would encompass design, prototype/pilot plant production, physical measurement and testing, and so on. Further, the engineering research here should not confine itself to the macroscopic world but examine the opportunities offered by novel new structures at the micro- and nano-level using advanced fabrication techniques for special applications. Advanced manufacturing technologies in this context would comprise not only those of mechanical engineering but extend into chemical engineering and off-site construction techniques now characteristic of the modern building.

Boundaries between the TSB technology pillars

Although an inclusive approach to technologies should ensure that important multidisciplinary research does not fall in the gaps between technological responsibilities, where does the boundary line lie between the ICT and DEAM pillars for research in simulation and modelling, for example, or for networked business processes? A simple answer would state that, as an example, simulation and modelling in the DEAM priority would focus on the applications of the available ICT to a particular problem while the ICT priority would seek to develop underlying technologies further. But a demanding application of a technology often pushes forward the underlying technology itself. In the manufacturing sector, there are examples of quite specific ICT, designed to manage supply chains or to deliver the special services related to a manufactured product over its life-span and recycling. But, in many more instances, generic ICT systems can find a variety of uses across numerous business sectors to meet various demands. In short, hard and fast demarcation lines cannot be drawn between technologies, and technology pillars must either work closely together or a more holistic mechanism sought to obviate the problem.

APPROACH AND METHODOLOGY

A simplified overview of the (manufacturing) business operations

A simplified view of a business would divide activities into three operations viz:

- Designing, simulating, modelling, validating the processes, products and systems of the business (validation may include rapid prototyping, small scale pilot production etc and necessary measurement and standards).
- Using the various production technologies/techniques to produce the 'components' and assembling/packaging these components into subsystems and systems in an optimal manner, taking account of interoperability and standards.
- Managing the business process including the supply chain, the services associated with the goods produced including life-time support and recycling/disposal/sustainability.

Every business in the DEAM pillar will have two of these operations and manufacturing business will have all three. The research necessary to support

these business operations can be classified under the three broad research headings described in Figure 1 on page 11.

Outline of the Initial Methodology

The present prioritisation has leaned heavily existing literature, in particular, on the results of Innovation and Growth Team (IGT) reports for major sectors such as aerospace and automotive, on other sectoral studies such as that on the modern built environment, UK and European Foresight-type studies (e.g. UK's Manufacturing 2020, EU's MANVIS) and recent European reports from the various ETPs and FP7 preparatory documents. Where no IGT report was available, advice was sought from intermediaries including officials knowledgeable on the particular industry or sector. Initial results have been discussed with groups of experts for related themes (e.g. the UK Manufuture Group) on an ad-hoc basis before circulation to a wider audience. The various elements and information flows making up the consultation process, including both national and European components like the MAS, are illustrated in Figure 2 on page 12.

Results of the initial DEAM technologies analysis

The results for this process are set out below under the headings of:

- New business models for enterprises.
- Design, simulation and modelling, validation and advanced erngineering research.
- Advanced manufacturing technologies.

New business models for enterprises

Globally-competitive companies have business strategies which their competitors find difficult to copy. Competent companies use technology, and ICT in particular, to give them 'operational efficiency'[4] in their business processes but world-class companies incorporate their ICT so as to continually reinforce their overall strategic framework. Evidence presented previously argues that European enterprises use ICT less effectively, on average, than their USA competitors in their business operations and strategies. New business models are needed to help leading and near-leading companies to maintain and improve their competitiveness (Manufacture 2020, MANVIS, FuTMaN, Manufuture)

The ICT topic covers organisational and service aspects of manufacturing enterprises and broadly deals with all issues surrounding the connectivity of businesses and people (be they employees – in 'collaborative working environments' or suppliers and customers in 'networked businesses processes'). As such, much of the research featured here will be developed with a view to incorporating new ICT tools to improve responsiveness and efficiency which could extend to the design of the manufacturing plants themselves. Topics of interest identified by high value-added sectors include:

- Network business processes for control and management of global supply chains: maintenance and monitoring systems e.g. for through-life support (Aerospace IGT)[5].
- Overall system design for low investment, intermediate volume manufacture; condition monitoring during processing, assembly and service (Automotive IGT)[6].
- Integrated business and design tools for collaborative working between project teams and clients on building structures, sustainability and changing functionality; networked management of production/delivery of building structures (linking logistics, lean construction and effective off-site manufacture of components (MBE)[7].

The key dependency for this area of the theme will be that with ICT where developments in knowledge/data management techniques, virtual/collaborative environments and communication technologies will be critical.

Design, simulation, modelling, validation and advanced engineering research

This topic covers a variety of engineering challenges ranging from the design, simulation and modelling (DSM) of components and entire systems, to validation using virtual or real entities (including those from rapid prototyping or testing using pilot-scale facilities). A few examples of the technological challenges identified by high value-added sectors include:

Aerospace: aerodynamics and propulsion systems; advanced and smart structures (and materials); adaptive/autonomous control and management systems; and management and prognostics of complex systems such as air traffic management (ATM).

Automotive: research associated with the improved performance of the internal combustion engine; electrical and mechanical energy storage for propulsion; noise reduction; vehicle weight reduction; integration/validation activities focused on electro-mechanical systems; and vehicle-human-interface and interactions .

Modern built environment: networked DSM and logistic tools for improved application/functionality for specialist applications e.g. hospitals; tools for in-use building monitoring and whole-life operating costs; virtual prototyping tools and use of avatars; and DSM tools for flexible future use of buildings including deconstruction.

Instrumentation: design of novel instrumentation for analytical tools and large facilities.

Marine: wave impact, hull design; propulsion and routing.

Rail: noise/vibration and emission reduction; vehicle weight reduction, propulsion and traction.

Transport services: transport system modelling and integration.

General: improved non-destructive testing of components, structural testing and monitoring of large sections; rapid, non-contact measurement, inspection and characterisation of components and systems.

As before, the developments here are contingent on the incorporation and use of new materials, ICT, electronics and energy technologies and should identify opportunities for metrology and standards.

Advanced Manufacturing Technologies (AMT)
There is obviously a close link between DSM and production processes, since technologies such as rapid prototyping might easily find application for small batch size production. AMT covers the following broad categories:

- Research associated with specific manufacturing technologies such as direct write (supported under the November 05 competition); near-net-shape forming technologies.
- Processing and associated intelligent control systems including distributed networked sensors and use of radio-frequency identification techniques.
- Advanced structures ranging from the very large structures of the aerospace industry (e.g. wings for airliners) to specially engineered surfaces creating desired macroscopic properties down to micro- and nano-structures.
- Novel methods of cleaning, joining, jointing and forming structures with potentially widespread applications.

Automation and in particular robotic systems especially low-cost robotics to increase automation and flexibility in SMEs and/or robotic systems with greater cognitive awareness so enable their increased use close to people;

- New approaches to standardisation of components and manufacturing techniques especially to reduce waste, enable re-usability or recycling.

Interoperability, standards and metrology remain a limiting factor to obtaining full benefits of integrated manufacturing systems. Although a considerable amount of work is already undertaken within the UK by the BSI and others, the challenges of interoperability are universal and would be better tackled at the EU level through the research Framework Programme.

SUMMARY OF PROPOSED DEAM PRIORITIES

Technology priorities: bringing together the results from various studies referred to above together with information from the core group of departmental and Research Council officials, the list of technology priorities is summarised in Table 1 on page 10.

European/Global Issues: during 2005 the European Commission put forward its draft proposals for the Framework Programme 7 (FP7) for research, technology development and demonstration. Although the Member States, European Parliament and the Commission have still to finalise an overall budget for the European Union for the period 2007-2013, the research

budget could increase substantially, from about €20 billion over four years in FP6 to about €48 Billion over seven years in FP7. The technologies of interest to the DEAM are located both in the Information and Communications Technologies programme (formerly the Information Society Technologies (IST) of FP6) and the Nanotechnology, Materials and Production Processes (NMP) programme. Although these programmes have differing technology priorities, they have co-operated successfully in FP6 through two joint calls for proposals in manufacturing technologies totalling about €180 million and IST has spent over €200 million on ICT for business processes, including simulation, virtual reality and grid computing for complex problems. No national programmes have either the resources or funds to support research on the scale and technical ambition of community programmes. National programmes should help prepare participants for Europe by assisting national players develop their technological expertise in key fields, providing experience of collaboration and dealing with government. We consider that this should be an important objective of DEAM activities.

Indeed, some activities are global. For example, the development of global supply chains involves massive data interchange. Open, interoperability standards would facilitate such exchanges. But issues of interoperability standards can only be properly addressed at the international level, perhaps through the new round of the Intelligent Manufacturing Systems (IMS) programme, currently being negotiated, and which bring together partners from the European Union, Norway, Switzerland, the USA, Japan, Korea, Canada and Australia.

University/business links: The UK is well served by the quality of its academic research in engineering, in particular, by the large investments made by the EPSRC in supporting IMRCs and Grand Challenges. If the UK is to retain an advanced manufacturing capability then it is important that:

a) We maintain the quality of engineering research in UK universities and support collaborative research in leading edge applications as defined in Table 1.
b) We encourage business to make better use of the applied research infrastructure, for example, by linking IMRCs with business through a Knowledge Transfer Network. This, in turn, could then link up with the Manufacturing Advisory Service (MAS) and provide the MAS with latest information on developments in manufacturing technologies for much wider dissemination to the UK business community.
c) We encourage the wider deployment of new techniques and processes by ensuring that the standards and metrology infrastructure and programmes play a complementary role in supporting the introduction of novel manufacturing processes and products.

TABLE 1: SUMMARY OF PRIORITIES

CALL DATE	TOPICS	UK REFERENCES	OTHER REFERENCES
April 2004	Environmentally friendly transport (£10 million)	AeIGT, AIGT	
November 2004	Design, simulation and modelling (£17 million)	AeIGT/AIGT	ManuFuture 2020
April 2005	Validation of complex systems (£60 million) Rapid prototyping – direct-write (£5 million)	AeIGT/AIGT/ Manufacture 2020	
November 2005	DEAM topics covered under other pillars including power electronics and electric power control systems		

TECHNOLOGY AREA	TOPICS	UK REFERENCES	OTHER REFERENCES
ICT/DSM/Adv manufacturing	Lean manufacturing and processes (resource efficient/ low cost/sustainable manufacturing processes)	AIGT/MBE	Manufuture
ICT for business processes	Digital manufacturing businesses (incl. collaborative environments/networked business/through-life services)	UK Foresight/ AEIGT/AIGT	MANVIS/ManuFuture
Design simulation modelling	Fluid flow/fluid dynamics	AeIGT/AIGT/MBE/ Chemicals	
Design simulation modelling	Design for reliability/availability and maintainability/through-life support/health management and prognostics	AeIGT	
Design simulation modelling	Design, simulation and modelling of advanced structures (including micro and nano-structures)	Manufacture 2020/ AeIGT/etc	
Design simulation modelling	DSM/validation of complex systems/design for assembly, disassembly, and recycling	AeIGT/AIGT/MBE etc	
Design simulation modelling	Validation incl. non-destructive testing from components to large sections; rapid, non-contact measurement and inspection	AeIGT/NPL	
Advanced manufacturing	Advanced forming and assembling tools and techniques (incl robotics and flexible automation)	AeIGT/AIGT/MBE/ Chemicals etc	
Advanced manufacturing	High speed processing technologies/rapid large-scale design and manufacture		
Advanced manufacturing	Advanced manufacturing technologies for micro- and nano-systems		
Advanced manufacturing	Advanced instrumentation and control/use of RFID engines and drive systems	PPARC/NPL	

FIGURE 1: RELATIONSHIP BETWEEN DEAM AND OTHER TECHNOLOGY AREAS

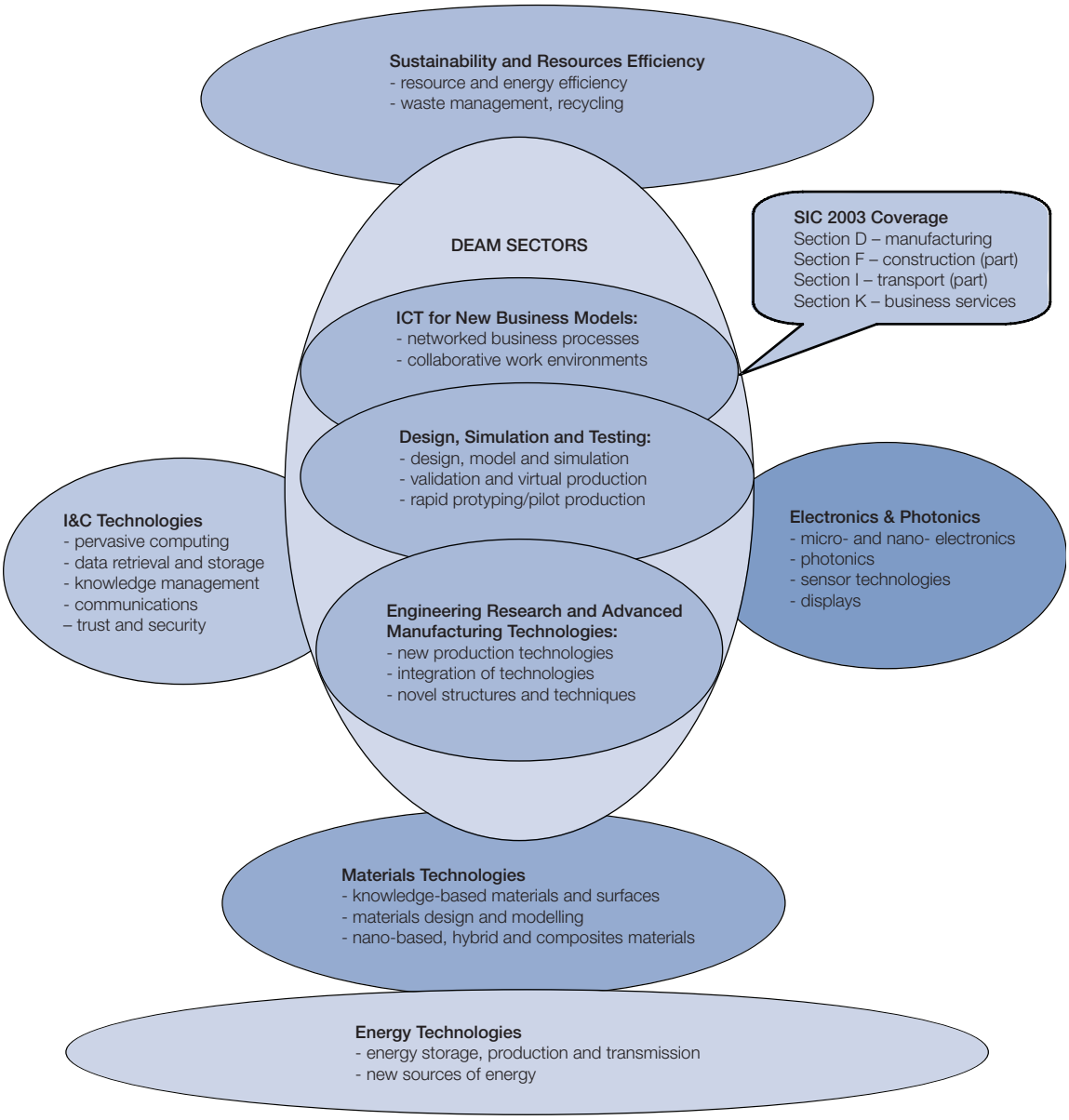
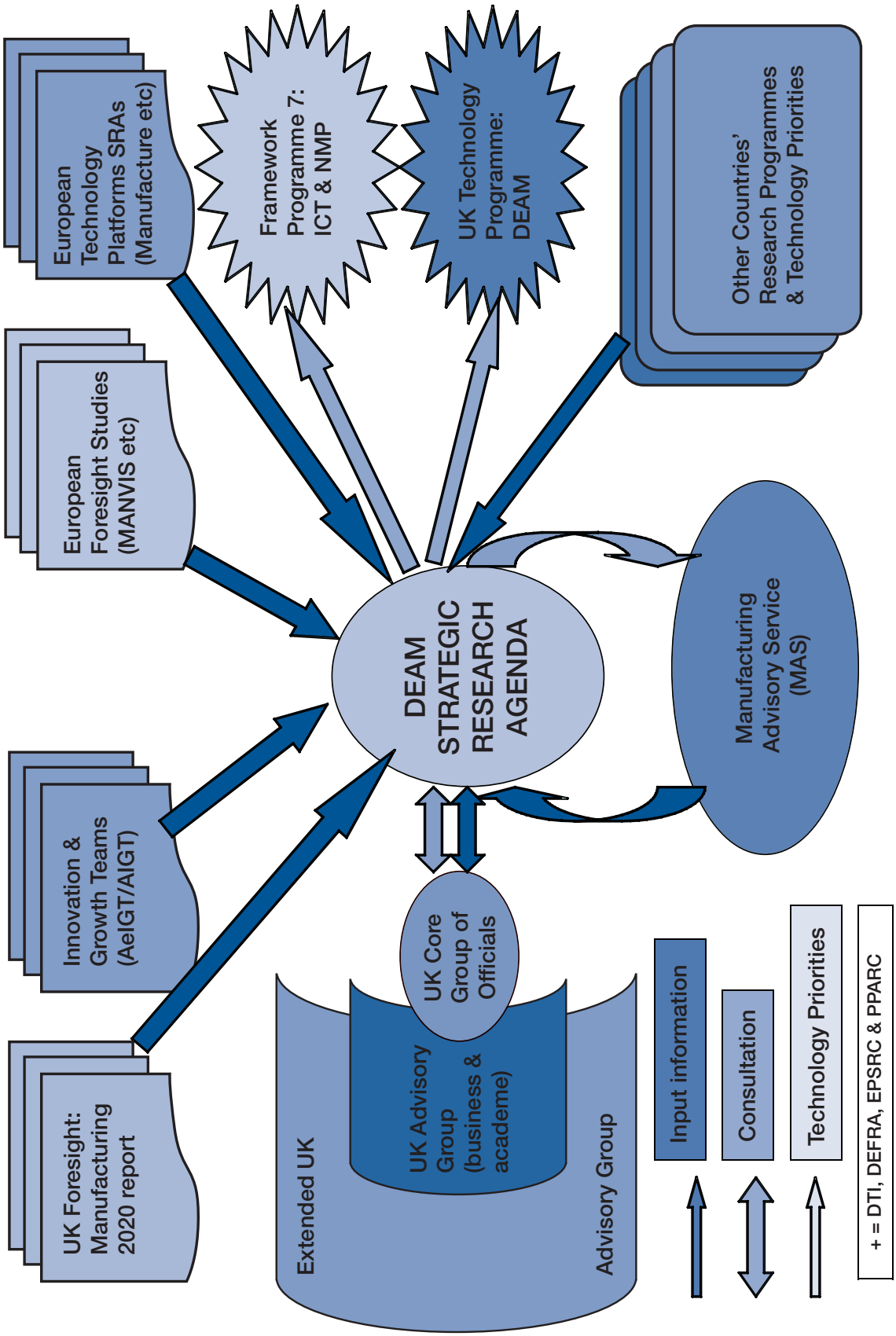


FIGURE 2: RELATIONSHIP BETWEEN DEAM AND OTHER TECHNOLOGY AREAS



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1 Productivity at macro economic level expresses the GDP per capita.
2 'The Policy Agenda for Growth' and 'The Sources of Economic Growth in OECD Countries', OECD, 2003
3 'ICT Investments and Growth Accounts for the EU', van Ark et al., 2002
4 Professor Michael Porter distinguishes between 'strategy competitiveness' and 'operational efficiency'; operation efficiency depends on the use of technology so can often be duplicated by competitors whereas strategic competitiveness comes from a combination of strategic vision, unique skills , and other attributes in combinations that competitors find difficult to copy.
5 Aerospace Innovation and Growth Team
6 Automotive Innovation and Growth Team
7 Modern Built Environment National Platform