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What are the significant trends shaping technology relevant to manufacturing?

Future of Manufacturing Project: Evidence Paper 6

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What are the significant trends shaping technology relevant to manufacturing?

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Contents

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Executive summary

This report reviews the major trends and technologies that are occurring and will affect the manufacturing sector. In reviewing the trends and technologies the discussion focuses on how significant they are to the global economy, developments over the last 40 years, current issues and predictions for the next 20 years and beyond.

The Technological trends include Automation, Digital integration, Electronics and Communications, Materials, Modelling and Simulation, Rapid Changeability, Rise of the Web and Raw Materials.

The key economic trend which is thought likely to affect manufacturing is Global supply chain management whereas the key sociological trend is individualisation and personalisation as customers demand products that are specifically designed for them. There is also the key environmental trend of sustainability as the population becomes ever more concerned with the world around it. Many of the trends appear to be converging around IT and the Web/Internet which are quickly becoming the basis for most manufacturing.

The report covers a total of 16 technologies ranging from Additive Manufacturing to Virtual Product Creation. The UK is very strong in many of these technologies and in a good position to exploit them in manufacturing. The UK has a strong reputation for design innovation. If this could be better linked to the areas of Additive Manufacturing, advanced design methodologies and tools and advanced supply chain management then there will be many opportunities for new products and manufacturing facilities located in the UK.

One of the recurring themes with many of the technologies in this report is a concern over the perceived lack of skills base in the UK to fully exploit the opportunities. Connected with most of the technologies the skills shortages range from craft and technician level to Doctorate. There may be some benefit from a government department studying each technology to determine how the skill demands will be met at all levels. There then needs to be a clear plan to meet these demands.

There could also be a benefit from rethinking the way technologies move through the technology readiness levels from basic research to product launch.

1. Introduction

This report is split into 2 main sections. The first section reviews the major trends that are occurring and will affect the manufacturing sector. These trends are technological, economic, sociological and environmental. The second section studies the main technologies that are likely to have greatest impact with Advanced Manufacturing. The report ends with conclusions that contain some suggestions for UK policy.

2. Major trends

2.1 Technological trends

Automation

Significance in the global economy

The worldwide market for automation products and solutions is around £188 billion growing to £500 billion by 2020, around 8% of total ICT expenditures (Pereira 2009). Factory automation is the largest sector of this market at 38%. The European automation market is around £62 billion. Over two-thirds of this market is composed of engineering services (i.e., application design, simulation and modelling, integration, installation and maintenance), growing at around 10% annually. The potential market for engineering tools, thru-life services and control/service infrastructure is estimated to be over £120 billion globally, and applicable in diverse domains, making it resilient to economic down-turns. This market is predicted to double in 5 years and robust growth is predicted even in the current economic climate (Pereira 2009).

Synopsis of manufacturing trends over last 40 years

Prior to the 1980s, automation systems were predominantly based around hardwired relay logic panels for their control. By the mid-80s computer-controlled industrial automation in the form of programmable logic controllers became economically viable, originating in the automotive industry and then becoming more widely utilised. This period also saw the initial practical utilisation of robotic systems. Up to the mid-80s the rate of change of products was relatively slow, and hence automation systems did not need to be particularly flexible or reconfigurable. By the end of the 1990s, product change on a yearly basis had become much more common, and this correspondingly placed a need on production automation systems to be more flexible and reconfigurable. By around 2005, the concept of reconfigurable manufacturing systems was well accepted and established in a number of industrial sectors. In order to enable the required reconfigurability, automation systems had progressively become more modular as the cost of computing systems progressively fell (Bi et al. 2007, Harrison and Colombo 2005).

Current issues in manufacture

Although modularity in automation systems hardware is now evident, there is a lack of effective design and lifecycle tools and compatible control system architectures to support the engineering of such systems. This is evident in an inability to retain knowledge about such systems and capture lessons learned. There remains relatively poor integration with business systems. Shop floor systems remain predominantly vendor-specific. These factors limit agility and make the cost of change higher than it should be (Vera et. al. 2009).

Automation for manufacturing 20 years from now

Within the next 20 years virtual engineering and commissioning of automation systems is likely to become viable in most application domains. Knowledge capture and reuse could also become well established. And there is potential for proper integration between product design and production system engineering. From the control system configuration perspective, distributed control is likely to become commonplace with more and more utilisation of wireless networking. There is also potential for the widespread adoption of service-oriented architectures and better cross-supply-chain systems engineering practices, where cloud-based computing methods can be utilised (Park et. al. 2009, Uddin et.al. 2011). The ever increasing demands for safer workplaces and the ageing workforce will also mean that automation will take over some of the existing manual tasks.

Automation for manufacturing 20 years beyond that

In the long term, there is potential for self-configuring production systems, which can adapt to process requirements, coupled with fully distributed control architectures, which could be embedded into the component parts of production systems. Engineering services are also likely to become fully integrated with the delivery of automation systems. Knowledge bases will be commonplace and utilised for the configuration and lifecycle support of production systems, including their real-time control and monitoring (Candido et. al. 2011).

Digital integration

Significance in the global economy

Digital integration of business processes, manufacturing processes and supply chains allows factories with high paid workers in advanced countries to compete with lower skilled, lower paid workers in developing economies. Computer controlled tools allow manufacturing products to be high precision and high quality and potentially low volume driving towards mass customization of products. Furthermore it allows manufacturing at scales not possible with human controlled tools. Nano-scale engineering and bio-engineering are now producing viable products. Products, dependent on advances in artificial intelligence, such as autonomous robots, vacuum cleaners, grass mowers, drones, submarines and cars are already entering the marketplace. CEOs like Andrew Liveris of Dow Chemical and Jeffrey Immelt of GE, as well as Harry Moser, Head of the Reshoring Initiative, typify the many leaders in government, business and academia working to reverse the tide of offshoring (Economist 2013).

Synopsis of manufacturing trends over last 40 years

Digital integration of computers, sensors, analytic software and controllers has given rise to Computer-Integrated Manufacturing (CIM), where computers control the whole production process. The idea was promoted by machine tool manufacturers, selling CNC machines, the Computer and Automated Systems Association (CASA) and the Society of Manufacturing Engineers (SME) amongst others. CIM involves algorithms for system control, including modifying processes depending on sensing state and has led to the concept of “mass customization”. The components include CNC (Computer Numerical Control), PLC (Programmable Logic Controllers), DNC (Direct Numerical Controllers), robots, 3-D printers and computer networks. These are supported by Computer Aided

Techniques, such as CAD (Computer Aided Design), CAM (Computer Aided Manufacturing), CAE (Computer Aided Engineering), CAPP (Computer Aided Process Planning), CAQ (Computer Aided Quality Assurance), PPC (Production Planning and Control), Rapid Prototyping, ERP (Enterprise Resource Planning) and PLM (Product Lifecycle Management) systems. The rapid and wide adoption of smart phones and other hand held devices that can act as data terminals, sensors and communications platforms has also changed the workflow processes in factories and supply chains. For example, smart phones can read bar codes and other identifiers and send images and video to engineers in remote locations.

Current issues in manufacture

Key issues in digital integration involve 1) the standardisation of messages and protocols between devices, 2) robust query and storage of big data (both structured and unstructured), 3) analytics and modelling techniques for complex systems, 4) management of wireless spectrum within factories and other facilities, 5) security (physical and cyber) of complex information and control networks, 6) modelling the behaviour of complex networks, 7) Internet of Things (4 Ws – What, Where, When, Why).

Digital integration for manufacturing 20 years out

There will be re-imagination of product design, manufacturing supply chain and factory control processes driven by a secure, ultrahigh bandwidth, smart Web and high fidelity simulation processes. Artificial intelligence will be heavily used to control industrial processes and manage workflow. The Internet of Things will be achieved with visibility available for almost all business, financial, social and political events.

Electronics and communications

Significance in the global economy

Since 1960, solid state electronics and the whole computer and communications industries that rely upon manufactured semiconductor components has grown as a share of world GDP from a very small fraction to nearly 20% today. It is hard to think of any part of modern life that is not fundamentally changed as a result – commerce, education and even institutions as diverse as churches and prisons! The annual growth rate has typically been 7%, more than double the 3% growth in industry as a whole. In 2010 it is estimated that IT spend was \$3.6T out of a total world economy of the order of \$60T, and split equally between computing (hardware, software and services) and telecommunications. In turn they enable much of the rest of the global economy to operate at the scale and speed that it does.

Synopsis of manufacturing trends over last 40 years

The whole sector has been enabled by silicon integrated circuit manufacture, supplemented by compound semiconductor components for telecommunications for radio, radar etc. The silicon IC sector in turn has been governed by Moore’s law, an empirical observation that has become a self-fulfilling prophesy, that the density of transistors on a chip (a measure of computational power) will double every 2 years. This law has applied since the 1960s, but like all exponentials it has a finite lifetime, being encountered now in advanced laboratories and likely to impact manufacture within a decade, and in this sector the next 40 years will not be like the past. The basic fabrication technologies remain the same as 40 years ago, but the engineering capability, precision and throughput have increased at the very rapid rate needed to maintain Moore' law with an increasing manufacturing yield of the chips.

Current issues in manufacture

For 20 years, an international consortium has produced the International Technology Road Map for Semiconductors (www.itrs.net), revised every two years, with an update every other year. The technology and manufacturing challenges for the next 20 years are laid out in some detail, using the continuation of Moore's law as the starting point for assessing what needs to be ready when for this continuation to proceed. There are an increasing number of 'red boxes' in the Roadmap indicating an identified technology need for which there is no known existing solution (this in addition to the 'amber boxes' that indicate that there are solutions known in principle, but not engineered to a state appropriate for manufacturing).

In recent years the Roadmap has branched out from solely a 'More Moore' focus to include a 'More than Moore' focus. This is a reflection on the greater need for devices that do more than just compute or store information, as in transit-receive modules for communications links.

In the top 25 semiconductor companies the only European entries are STMicroelectronics (French/Italian), Infineon (German) and NXP (Netherlands) the only European entries at 7th, 12th and 16th place: together they account for only $18B out of $311B sales (Ford 2012). A searchable list of 818 major semiconductor companies is also available (www.digchip.com/datasheets/manufactures.php).

The value of the semiconductor element in any electronic product is often quite small (~20% in laptops), but this element dictates the overall performance. Displays represent the other high-end component of most electronics or communications equipment.

The evolution in displays has been described as rapid growth but slow in changing (Semenza 2012). The sector is dominated by the $100B LCD-TV business, but this sector is not expected to grow over this decade as fast as in the previous two. The core enabling technology patents were British, and there has been some involvement in both the glass and the liquid crystal developments, but no significant manufacture.

There are mission critical materials – for electromagnetic screening and thermal management which supply into the computing and telecommunications sector. The UK's Laird plc is a major global player but has all its manufacture in China, Mexico and the Czech Republic.

Electronics and communications for manufacturing 20 years out

The last 20 years have been dictated by the rise of handheld electronics and the internet. (Note that both were in existence but relatively embryonic in 1990, and have become pervasive since then). Both sectors involve large scale manufactures of the individual devices and also the larger infrastructure elements. In turn they support an enormous services support industry, and the whole software sector to build useful applications. Both streams are expected to continue over the next 20 years with an ever increasing richness of applications.

The one area that is embryonic now but scheduled to become pervasive over the next 20 years is that of integrated sensor networks (usually with wireless connectivity) to enable such radical new opportunities as autonomous vehicle navigation in city centres and city-level load-balancing of electricity demand. The key components of the technology exist, but the infrastructure, roll-out and uptake will take two decades to become pervasive.

The automobile sector will remain important, with each car being a node on the internet, receiving and sending information: the value of on-board electronics overtook the value of the chassis and body steel a decade ago.

Towards the end of this period, the conventional Moore's law scale of improvement in computing power will cease to hold. The manufacture of chips will become commoditised, with the differentiation being at the architecture level for a short period, and then at the systems-on-a-chip level for another short period. In the longer term a renewed focus on the efficiency with which modern software uses the silicon real estate (a factor abandoned in the late 1970s as memory space grew) will allow end-user to experience increased computational power from the same underlying physical platform. The whole sector will follow down the same route and shipping and air-transport that had their 'Moore's law' eras that finished in 1943 with the launch of the US battle-cruisers and 1969 with the launch of the jumbo jet. Diversification of product types and slow incremental improvements will replace the compound growth of the previous 50 years. This may allow new players to enter, but the economics of manufacture will trump the technical performance in deciding where products are made.

The bandwidth capability of telecommunication over fibre still has some way to go, but on the same 20 years' timescale, this too will constrain progress. Over that timescale free space terahertz radiation that has very wide bandwidth, but very low range due to strong atmospheric attenuation of the low initial broadcast powers, will be distributed to near the point of use over optical fibre. Again the system components are capable of manufacture now, but the roll-out and take-up will take 20 years.

Work on plastic electronics has not delivered at the scale once hoped, and the reasons are to do with the fundamental capability of the new materials in direct competition with the incumbents.

Electronics and communications for manufacturing 20 years beyond that

The research space of nanoscience is global, with ideas for new devices and subsystems covering all possible areas of application, including such radical ideas as brain-electronic interactions. The problem with nearly all current ideas is that the present means of fabrication are intrinsically unsuited to scale up for high volume low cost manufacture (Kelly 2011). Some real breakthrough is needed in this area before this work will have any real-word impact.

Quantum computing has been actively research for 20 years now, with the theory running far ahead of the experimental work, which itself is far ahead of the technology. Specialist applications, such as quantum cryptography, are already available, and are likely to become pervasive. The intrinsic high power of quantum computing is such that high-cost fabrication paradigms may replace the current ethos that favours low-cost high volume manufacture.

Otherwise mainstream silicon chips technology will remain pervasive and commoditised like products of steel (aluminium) of the 18th/19th century.

The current UK strength is in places like ARM which licences the chip design in over 95% of the world's mobile phone, CSR with a strong position in Software Radio, and Autonomy, the smart software company recently purchased by HP. Electronics and communications are inherently global, and manufacturing will tend to go to low costs countries until automation renders lower skilled labour less significant, which may occur over the next 20 years (see automation). The UK will do well to focus on new ideas and design in the short and medium term. In addition there is much more employment in exploiting new technologies rather than developing or manufacturing them. The whole of the current software and services industry is a clear example of this. In the longer term a closer link between hardware and software (post Moore's law) may bring new opportunities in the area of integrated sensor networks where the UK might choose to focus.

Materials with novel properties

Significance in the global economy

Materials underpin every manufactured product in the global economy, and in many applications it is the specific materials properties that give a particular product the edge in the marketplace. As we see below, the range of commercial products has expanded greatly over the last 40 years in part because they are made possible with new materials with novel properties. Almost any domestic appliance from a radio or telephone, through white goods to fabrics and furnishings still perform the same basic function, but with greater convenience, efficiency, attractiveness, etc. There is also a greater range of synthetic materials to replace older products made in natural materials or simpler metals or ceramics.

Synopsis of manufacturing trends over last 40 years

Rather than list the new materials with new properties in the domestic and transport arenas over the last 40 years, the focus here will be on whole classes of new materials with novel properties that have emerged. Those discussed here do not exhaust the possibilities.

In the last 20 years there have been an explosion in the types of soft materials that have become available, from the paste for post-it notes that never quite adheres or dries, polymeric materials that conduct electricity and/or emit light, gels of a great variety, etc. In addition fluids with novel rheological properties have been obtained. Other developments include materials with different types of gradient properties (optical, mechanical, thermal), hyperflexible wood notepads, newspaper woods, phase change (translucent to clear) materials, carbon negative concrete, noise quenching curtains, liquid wood chairs, metal origami, with flat-pack sheets that assume myriads of shapes, self-healing concrete, 3D but flat-packed concrete structures (Dornob, 2013).

Composite materials were developed in the 1960s and have been improved ever since, transforming sports such as tennis, and even becoming body parts for aircraft as specific properties, including impact damage limitation have improved. Liquid crystals started out as exotic materials at low temperatures and ended up as the key element in the $100B electronic display industry.

Current issues in manufacture

The list of novel materials that are being developed using nanotechnologies alone is long and includes: surfaces with anti-microbial coatings for safer medical equipment; safer food packaging and storage; easy-to-clean windows requiring less detergents thus reducing pollution; anti-scratch coatings for the car industry; anti-fog and anti-fingerprint coatings for improving materials in for example eye glasses and windows in cars; surfaces that resist corrosion and materials that wear and tear less; textiles with improved strength, fire protection and flame retardancy for safer clothing; lightweight metal materials to be used for building lighter yet stronger parts for airplanes, cars, turbines for windmills and petrol tanks; materials with better insulation properties to reduce heat dispersion of homes and offices during winter; photochromic materials that use heat to darken windows in summer to use less air conditioning; new thermoelectric nanomaterials that convert heat into electricity; nanocomposites for the production of sustainable cement; biocompatible nanomaterials for bone and dental replacement and many more (Inscience 2013). Some are in the market place and others are on the way over the coming decade.

A huge growth in biocompatible materials is finding many uses as implants, dissolving sutures, artificial ligaments, drug release controllers, and eventually direct muscle-electronics interfaces for actively controlled prostheses.

Artificial materials not known in nature, such as multilayers of two different semiconductors, with atomically abrupt interfaces, have become ubiquitous in electronic devices, and the current power of silicon technology, solid state lighting, infrared detection, lasers and microwave and radar communications are intimately associated with the use of high-quality semiconductor interfaces.

Materials with novel properties for manufacturing 20 years out

A whole class of new materials, meta-materials, are being made out of two-and three-dimensional arrays not of atoms, but of major clusters of atoms, and these will produce even more new materials capability once the manufacturing techniques are mastered. Negative refractive indices have developed with arrays of mm-scale artefacts, but once this is miniaturised by a factor of 100 in two or all three dimensions, the optical, electronic, magnetic, thermal, elastic and other properties will be tuneable, and in some cases switchable (e.g. from clear to opaque or conducting to insulating etc.). Early examples of artificial acoustic materials are available in the laboratory. These will emerge into the market place over the next 20 years.

Over the next 20 years, Moore’s law of miniaturisation will reach the fundamental atomic limit in size, the crossover point where the increasing cost of miniaturisation is not exceeded by the value of the resulting product. This in turn will place limits on the economic tailorability of artificial materials and produce a clearer boundary between what is, and is not manufacturable; at present this boundary is ill defined. That will not stop further research into alternative ways of manufacture, at both small and large scale, but it will be subject to different drivers.

The basic theory of simple materials places limits on hardness, elasticity and other basic properties of materials. Earlier manufactured materials, such as elemental metals, and the simply binary alloys made from them, have reached limits of performance as observed empirically. Over the next 20 years this understanding will extend to more complex materials properties or more complex materials, either through theory or simple observation. For example, in spite of many attempts, no set of quantum dots has been ever prepared with a standard deviation of less than about 15% by volume for dots of typical diameter 5nm. It is still not clear whether this is a fundamental limit imposed by the statistics of small numbers, or some deeper kinetic or thermodynamic reason.

Materials with novel properties for manufacturing 20 years beyond that

It is likely that the dematerialisation of manufacture – getting more for less – will continue over the next four decades and beyond. The full exploitation of many aspects of materials science, including hardness, phase changes, pairs or triples of specific properties (acousto-thermal, colour-stress, …) are still to be achieved. In our section on the manufacture of sensors this will become more apparent. While the shelf-life of many products has become shorter in the age of electronics, a return to a longer lifetime products may occur if the electronic updates become software only. In turn the longevity of new materials in service may need further investigation on the timescale of 40 years. For example, the in-situ monitoring of aging infrastructure may require optical fibres to last for many decades.

The drivers for new materials will remain much as they are now, superior performance at any cost for the most elite applications (as in sports equipment, Formula 1), followed by manufacture at reduced cost for wider applications in the market place. Environmental concerns will drive the more sustainable use of materials, and favour materials and products that prove their sustainability through less resource use, ease of recycling etc. The current rise in multifunctional materials, ones where combinations of properties are used to do two or more tasks is an appropriate area for UK focus. It is higher end in value, and in the early days, the scale of UK production of advanced prototypes and early deployment fits with the UK scale in the world.

Modelling and simulation (M&S)

Significance in the global economy

Modelling and simulation (M&S) are playing an increasingly important part in manufacturing at the stage of design and optimisation. As a result, development of respective software tools became an industry in itself, with major players employing a significant number of specialists. The remit of M&S is continuously expanding, with the recent years witnessing an accelerated introduction of new M&S tools by established software manufacturers as well as a rapid increase in the number of start-ups, consultancies and research groups developing their own in-house tools – both for themselves as well as for their partners or external users. Though there is still no transition to a full ‘virtual reality’ that has been promised for several decades, there are some significant achievements affecting and transforming many traditional engineering procedures. Two major points are making M&S extremely attractive: (i) significant speeding up of the developments cycle (i.e. reduction of time from an idea to its implementation, that is very important for very complex platforms and products, e.g. in aerospace and naval industries) and (ii) substitution with simulations of some of real-life tests necessary in many cases for approval of new materials, designs, platforms etc.

High fidelity simulation can model how future factories and systems will function, thereby holding costs down and decreasing errors. This is important because investment costs are high and the tolerance for errors is low. The concept of the "virtual machine", the "virtual factory", the "virtual warehouse", the "virtual supply chain", the "virtual Smart Grid", the "virtual global IT system", can now be implemented in software.

Synopsis of manufacturing trends over last 40 years

M&S was a relatively established area of activity even 40 years ago, with most important manufacturing-relevant approaches – computer-aided design (CAD), finite-element analysis (FEA) and computational fluid mechanics (CFD) – available in various (although rather simple) forms, including commercial products of established software manufacturers (FEA) or in-house/research tools and packages. Still, due to constraints in computing power, only relatively simple problems were routinely solved. Advanced FEA and CFD simulations were performed predominantly with mainframe computers by academic researchers (in many cases with a doctorate) or specialised teams or departments of high-tech companies (mostly defence and aerospace). In most cases they were underpinning or advising design rather than being used directly as design tools. A continuous increase in computational power and reduction of hardware price (the Moore's law) changed this pattern, with structural integrity problems being currently routinely solved by industrial engineers. In the last decade or so, there has been an apparent process of convergence of remits of many software products to incorporate features that in the past were specific for some specialised and niche products. The main current trends are: (i) a significant increase in the number of built-in options and tools; (ii) parallelisation that allows speeding up computations by using multiple processors; (iii) an option of user-defined operations and routines allowing researchers to adjust software for their specific aims; (iv) active interaction of main software manufacturers with such researchers and (relatively) swift incorporation of their routines into commercial codes; (v) multi-scaling, i.e. bridging various length and time scales to account for underpinning mechanisms; (vi) a transition to so-called multi-physics, i.e. dealing not with a single field (e.g. mechanical, thermal, electrical etc.) but with several, including their interaction (so-called coupled problems). The last feature is causing, for instance, convergence of FEA and CFD in dealing with solid-fluid interaction. On the other hand, open-access (or open-code) developments result in full packages or specialised tools available freely on-line. Systems dynamics is popular but its predictions have been problematic and have not born the test of time. Discrete event simulation, agent based simulation and holonic multi-agent systems are all areas that show promise for modelling complex systems.

Current issues in manufacture

Though M&S is a rather established field of activities, supporting – directly or indirectly – manufacturing, there are still some major challenges preventing a broader use of modelling and simulation by industry (especially, non-high-tech companies):

- Computational speed/efforts – Most simulations of complex problems still take a significant amount of time and computational effort. For instance, calculations accounting for atomic microstructure deal with volumes with a dimension of single microns, while so called 'first-principle' simulations are still limited to even smaller volumes. Even an analysis of moderately complex deformation behaviour of a specimen can take days or weeks of simulations with high-performance clusters.

- Materials data – Although there is an increasing number of materials data available in printed and electronic form (including built-in materials databases in commercial software packages) for conventional materials under traditional loading/usability conditions, more advanced (and more adequate) models depend on the data that are hard (and expensive) to obtain, e.g. employing micro computed tomography and neutron scattering to quantify microstructure and spatial distribution of its features. There is a lack of data for conventional materials under more challenging loading/usability conditions.

- New materials – There is an accelerated introduction not only of new materials but even their new classes into various applications, with areas of material characterisation and M&S being overwhelmed with such developments. A typical example was a shift to lead-free microelectronics in 2007 when properties and performance of new solders were insufficiently studied at the moment of their introduction into products.

- Lack of high-skilled specialists – Though CAD, FEA and CFD are now a part of standard syllabi at universities, more advanced simulations are still performed mostly by academic researchers. Software user interfaces, though much friendlier, still need extensive training while the user-defined subroutines presuppose the knowledge of high-level programming languages.

M&S for manufacturing 20 years out

The main focus is currently on development of either universal or highly specialised software tools. In the next 20 years, as a result of convergence, main commercial software packages will cover most applications. The interface will become more user-friendly, following the spread of ICT products, gadgets and apps into our everyday life. The unit cost of computation will continue to decline. This will allow implementation of most features of ‘virtual reality’.

The main focus will be on development of much more complex material models see, for instance Materials Genome Initiative (National Science and Technology Council 2011), launched by the US Government in 2011 to allow not only a better use of materials in components and structures but also development of new materials, tailored for specific applications. An integrated CAD-CFD-FEA software package will become a standard tool for a designer.

M&S for manufacturing 20 years beyond that

M&S will be fully integrated into any design-manufacturing process, for any length scale (i.e. nano and micro-manufacturing) and complexity. Real-time predictions of performance and life-in-service will be part of integrated M&S capabilities. They will be also used for inverse problems – design of material-components or multi-material-structures for a required usability envelope with requested properties, performance and functionality.
Simulation will be used to "future proof" new systems such as Smart Grid and Smart Cities. Simulations of businesses will focus not only on the physical systems but also on

their IT and control systems. For example, Ford Motor Company simulates its global IT network that supports 24x7 design processes.

There will be a transition from simulating the "nodes" to simulating systems composed of billions of nodes and their interactions. Simulation of complex systems, e.g. in financial institutions, pose challenges in "Connection Science". Simulations produce large data sets that need to be queried and visualized. Visualization of large data sets will be important for human cognition (See Big Data).

Rapid changeability

Significance in the global economy

It has been highlighted that "In the 21st century manufacturing companies face increasingly frequent and unpredictable market changes driven by global competition, including the rapid introduction of new products and constantly varying product demand. To remain competitive, companies must design manufacturing systems that not only produce high-quality products at low costs, but also allow for rapid response to market changes and consumer needs" (Gola and Swic 2012).

As the lifecycle of consumer products has become shorter, it has become more and more important to be able to offer flexibility and/or reconfigurability in production systems provided via suitable automation systems supported by appropriate engineering tools and services. In high-wage economies rapid changeability within automated systems is thus of key importance. The worldwide market for automation products and solutions is around £188 billion growing to £500 billion by 2020, around 8% of total ICT expenditures (Pereira 2009). Factory automation is the largest sector of this market at 38%. The European automation market is around £62 billion. Over two-thirds of this market is composed of engineering services (i.e., application design, simulation and modelling, integration, installation and maintenance), growing at around 10% annually. The potential market for engineering tools, thru-life services and control/service infrastructure is estimated to be over £120 billion globally, and applicable in diverse domains, making it resilient to economic down-turns. This market is predicted (Pereira 2009) to double in 5 years and robust growth is predicted even in the current economic climate. Rapid changeability can enable enhanced manufacturing agility. For example, given rapid changeability, a major automotive company has estimated that potential savings of over 30% in ramp-up costs are achievable with a target of a 50% reduction in system commission time, potentially worth over £30 million per production line. The need to change over production occurs in many areas and this is being driven by a more recent trend to respond to customer needs and external drivers. However, in a study in 2009 it was found that 40% of companies were engaged in Lean manufacturing whereas less than 4% where involved in Agile manufacturing (Alexander 2009).

Synopsis of manufacturing trends over last 40 years

The typical approaches to satisfying product change were either to utilise predominantly manual assembly or to create more flexible and reconfigurable automated production systems, which were change-capable. This has been partially successful; however, most automation systems remain relatively difficult and costly to change rapidly for the accommodation of new product designs (Mehrabi et. al. 2000). Towards the end of the last century one of the main tools to achieve Rapid Changeability was the Flexible manufacturing systems (FMS) which was made up of hardware elements such as CNC machines tools and Software such as NC programs (Malhotra et. al. 2010). There was also the introduction of Quick Change Tooling to speed up changes on these machines. This became common in Japan for press tooling where standardised die sets were the key to implementation (Sprow 1984).

Current issues in manufacture

The hierarchy (Wiendahl et. al. 2007) of changeability in manufacturing has been described as:

- Changeover ability - designates the operative ability of a single machine or workstation to perform particular operations on a known work piece or subassembly at any desired moment with minimal effort and delay.
- Reconfigurability - describes the operative ability of a manufacturing or assembly system to switch with minimal effort and delay to a particular family of work pieces or subassemblies through the addition or removal of functional elements.
- Flexibility - refers to the tactical ability of an entire production and logistics area to switch with reasonably little time and effort to new – although similar – families of components by changing manufacturing processes, material flows and logistical functions.
- Transformability - indicates the tactical ability of an entire factory structure to switch to another product family. This calls for structural interventions in the production and logistics systems, in the structure and facilities of the buildings, in the organization structure and process, and in the area of personnel.
- Agility - means the strategic ability of an entire company to open up new markets, to develop the requisite products and services, and to build up necessary manufacturing capacity.

Changeability can be achieved either through more flexible automation, which can be reprogrammed or via reconfiguration of production systems. Modularity in automation systems is now commonplace; however, there is a lack of affective design and lifecycle support tools and related engineering services. Reuse libraries are needed to enable changeability to become well-established from a business perspective, and engineering tools and services to support the modelling and rapid configuration of such systems could greatly improve the cost-effectiveness of change-capable production systems. Although modularity in automation systems hardware is now evident, there is a lack of effective design and lifecycle tools and compatible control system architectures to support the engineering of such systems. This is evident in an inability to retain knowledge about such systems and capture lessons learned (Vera et. al. 2009).

Rapid changeability for manufacturing 20 years out

In the next 20 years, change-capable systems are likely to become well-established in certain application domains where modular production equipment is practical. Examples of this include the automotive sectors. Where very high precision or performance is required, design optimisation makes change-capable systems more difficult to realise. There is also potential for the widespread adoption of service-oriented architectures and better cross-supply-chain systems engineering practices, where cloud-based computing methods can be utilised (Park et. al. 2009, Uddin 2011). A Reconfigurable Process Planning environment will be in place to facilitate rapid changeability (ElMaraghy 2006).

Rapid changeability for manufacturing 20 years beyond that

In the long term, self-configuring production systems able to adapt directly to process requirements could become practical. Such systems would require advanced knowledge-based approaches to their configuration and lifecycle support. Engineering services are also likely to become fully integrated with delivery of automation systems. Knowledge bases will be commonplace and utilised for configuration and lifecycle support of production systems, including their real-time control and monitoring (Candido et. al. 2011, Stokic et. al. 2011, Lepuschitz et. al., 2011).

Rise of the web

Significance in the global economy

The "knowledge economy" and the more recent "innovation economy" are both dependent on the rise of the World Wide Web and associated ICT technologies, such as Google search, email and WebEx. Today's businesses rely on technologies such as WebEx and Microsoft Lync for managing collaboration and coordination of world-wide teams. Multinational companies regularly do "follow the sun" design. The rise of broadband allows "remote working" and additional flexibility for employees. In education the Open University model is now being radically extended to have classes with tens of thousands of people. eg Coursera, Udacity and EdX.

Synopsis over last 40 years

At the heart of the Information Age sits the indivisible combination of the Internet and the World Wide Web (WWW). The former originating in ARPANET, the packet switching network of computers created by the Advanced Research Projects Agency (ARPA) of the US Department of Defence in the late 1960's, and the latter the invention of Tim Berners-Lee at CERN (European Organisation for Nuclear Research) in Switzerland in 1992. The distinction is crucial to understanding cyberspace. The Internet protocol is TCP/IP and the Web protocol is HTTP. Today most of the world wide traffic of 600 petabytes is transferred via HTTP and a typical GET or POST request to a URL, such as (www.ft.com). This seemingly simple string has given rise to a whole new way of naming and discovering Web Servers and their associated data.

The URL locator www.ft.com?id=332&pageId=99&docID=574&cookie=6ab34d today contains query strings and authentication keys (cookies) so that a simple URL request can move money from one bank account to another, order a tractor to be manufactured or order a video, tune or book to be purchased and downloaded. The key facilitator in requesting and viewing data is the "browser" and the Web Server. Sensor networks and SCADA units are placed "on the Web" by running a small web server that is capable of fielding URL requests via HTTP. This means they can be controlled from a browser by simply issuing an HTTP request.

The "reach" of the browser has made it the most common programming platform in the world. The support for browsers on devices from laptops to smart phones means that data can be rendered into a browser and be viewable from these devices. The typical

Web page is today a block of HTML and JavaScript code. Of the 1 trillion URLs in the world a good proportion execute JavaScript. This has implications for the workforce of programmers. While C++, Java and C# are still popular for robust large scale software, it can be argued that the next generation of programmers will be educated in Javascript.

Current issues in manufacture

The present web was not designed with security in mind and the notion of well-funded cyber crooks as adversaries. While making sensor and machines web addressable has led to wide spread integration and visibility of components it has also greatly extended the attack surface. The loss of intellectual property in western countries over the last 10 years is not fully appreciated or measurable but it is known to be significant. The security fabric of the web is large single factor authentication (username and password). Although two factor authentication is rapidly becoming standardized for humans the problem of machine to machine authentication still remains. Today it is based on trusting certificate authorities and X.509 certificates. Both have been shown to be insecure under certain circumstances. Thus, there are serious issues that need to be addressed with respect to security before the full potential of the Web and the Internet of Things can be realized.

Rise of the web for manufacturing 20 years out

There will be a re-imagination of society, mega-cities, government, finance, news, entertainment, business, learning and leisure, driven by a secure, ultrahigh bandwidth, smart Web. The Internet of Things will be achieved and there will be visibility available for almost all business, financial, social and political events. This will cover (Meeker and Wu 2012):

- Social network profiling and preference-aware mobile applications;
- Intelligent mapping and navigation;
- Personal full-service assistants and organisers;
- Global collaboration with cloud computing storage and sharing;
- Audio, video and music online co-creation, sharing, storage and access;
- Social media synopsis and real time search arbitrage via intermediaries;
- Semantic search engines with decision making tools and data visualisation; and
- Unified yet distributed organic web strategies and presence.

Raw materials availability for manufacture

Significance in the global economy

All manufacturing starts with raw materials, and depending on the position in the supply chain, this may mean ores, refined materials such as metals, semi-finished materials, or even subsystems. In most cases, the availability of raw materials depends on geopolitics, and the regimes that run the territories where the materials are sourced. Today, access to rare earth metals is headline news, because of the accessibility of ores in China compared with other places, and some Chinese trade embargoes with Japan and elsewhere. Russia controls major supplies natural gas to Europe, although the fracking gas revolution may lead to reduced supplies. In other contexts legislation that prohibits sensitive technology from the US to certain regimes goes as far as accessibility to certain advanced materials.

Synopsis of manufacturing trends over last 40 years

Over the last 40 years, there have been political embargoes such as that applying to South Africa during the apartheid era. In wartime economies, as well, the role of substitute materials (synthetic rubber for natural rubber, synthetic fuel for petroleum imports) has come to the fore. In 1970 the Club of Rome listed 16 minerals and materials that would be exhausted by 2000, but this has not occurred: materials substitutions in response to rising raw materials prices, new discoveries of ore, recycling and run-down of stockpiles have conspired to counteract the perceived shortages. The efficient use of raw materials has always been a consideration in manufacture, but the more so as materials in perceived shortages of supply become more expensive to secure. Indeed it is wise to be cautious about shortages, as all neo-Malthusians have proved wrong down the years. The known reserves of oil and gas means that the world's proven reserves of these commodities have never been higher and are adequate for the next 40 years. See table 2 from (Sheraz 2001) for growth of reserves during 1950-2000:

Table - Evolution of mineral reserves and identified resources during the period 1950-2000

Mineral commodity	1950 **Mineral reserves & identified resources**	1974 **Mineral reserves & identified resources**	2000 **Mineral reserves & identified resources**	**Growth in 50 years (2000/1950)**
Copper	1.0×10^{8}	3.9×10^{8}	6.5×10^{8}	6.5x
Gold	3.0×10^{4}	4.0×10^{4}	7.7×10^{4}	2.5x
Iron	1.9×10^{10}	8.8×10^{10}	3.1×10^{11}	16.3x
Lead	4.0×10^{7}	1.5×10^{8}	1.3×10^{8}	3.25x
Tin	6.0×10^{6}	1.0×10^{7}	12.0×10^{6}	2.0x
Coal	6.0×10^{10}	6.5×10^{11}	9.8×10^{11}	16.3x
Oil (bbl)	8.0×10^{10}	7.2×10^{11}	1.05×10^{12}	13.1x
Natural Gas (m^3)	4.7×10^{12}	2.2×10^{15}	1.5×10^{14}	31.9x

Source: {USGS (several), BP Statistical Review of World Energy (several), The Petroleum Handbook, Royal Dutch/Sheel Group of Campanies, Fifth edition, 1966, IEA(several), UN-Statistical Yearbook (several)} as quoted by (Machado & Suslick, 2009).

Current issues in manufacture

Availability of raw materials has always been a strategic issue for manufacture. This will continue, but with continued evolution of how raw materials are obtained. The continued prospecting of new sources of raw materials continues worldwide. With some materials of greater value, the re-mining of old sites aims to use new methods of recovery to collect that which was missed first time round, with metals extracted from previous waste. Landfill sites are already a source of methane (Environment Agency 2013).

For fossil fuels, it is estimated that 1T barrels of oil equivalent have been used, an equal amount is in known reserves, and there is a further estimate that there could be anywhere between 3 and 5 T barrels as yet undiscovered (Eyton 2012, private communication). This estimate is supported by recent work of Hansen et. al. (2013) that shows the results of studies of both conventional and unconventional fossil fuel reserves, and the fact that only of order 10% of the total reserves has been used (see Figure 6 in this reference).

The appreciation that all material resources are finite, and especially those materials that can be mined easily, is leading to the increased awareness for recycling (DEFRA 2012). Initiatives at the EU level are promoting recycling to overcome materials shortages (Europa 2012) not least among the 17kg of discarded electronics per European per year. IBM have indicated that the concentration of gold and other precision metals in discarded electronics is already higher than in the original ores from which they were obtained. An industry is growing around recycled electronics, and the recovery of several relatively precious materials.

Further up the value chain, in the USA and elsewhere, there have been reports of shortages of pharmaceuticals because of the shortages of raw materials (Braunstein 2012). This is mainly a matter of supply chain management rather than intrinsic shortages of raw materials.

Design for deconstruction and reuse of materials will become more important, especially in sectors that are heavy consumers – e.g. automobiles with a rapid recycling time (Wahab et. al. 2008)) and even out to housing where higher energy efficiency standards mean that Chinese houses with 30 year life-spans will be replaced rather than retrofitted (Guy and Williams 2003). We have a separate section on sustainable use of materials where these same issues are replayed.

Raw materials availability for manufacturing 20 years out

There will continue to be temporary shortages of materials, even strategic materials, because of sudden surges in demand, political embargoes, etc., but our concern here is the implications of a gradual depletion of large but finite resources. The market sends price signals that over time give impetus to materials substitution, and this trend over the last 40 years will continue over the next 40. The availability of new synthetic replacements means that plastics have replaced metals in most containers. In the pharmaceutical industry, generic drugs are replacing proprietary drugs both to maintain supply and reduce costs. Such materials substitution will continue whether driven by scarcity or cost or both.

General environmental concerns that aim to maintain the earth's ecosystems from multiple threats are resulting in an increase in the degree of recycling of materials. This has now reached out from the manufacturing sector to the domestic sector where much of the consumption occurs. Landfill taxes are used to accelerate this process by putting an extra value on avoided waste.

The dematerialisation that has occurred in electronics will continue where one smart phone now has the contents of a former separate camera, calculator, GPS monitor, recording system, games console, book, etc.

A systematic study has been made of the potential for resource efficiency in manufacture and use, and the 'Top20' (Rohn et. al. 2009) include new light construction materials, chemical product methods, steels, nanotechnology enabled surfaces, adhesives (especially for the construction sector), IT, fibre substitution, energy sources etc. On the timescale of 20 years some of these new approaches will have been adopted and some will have become both established and pervasive.

One sector that is likely to have grown beginning on this timescale will be products that offer bio-inspired assistance for everyday living, in parallel with the growth of an aging society. The sourcing of bio-compatible raw materials may emerge as new part of the sector. Unlike plants for fuels, the source materials are likely to be high value-added and in small total volumes, and so not pose a threat to the land needed for foodstuffs.

Raw materials availability for manufacturing 20 years beyond that

As the fundamentals of manufacturing have not changed in respect of sourcing raw materials in the last 40 years, it is likely not to change radically in the next 40, even given the likely expansion of manufacture for a larger population. The business as usual pressures will be to use less material, to use it more sustainably, and to recycle wherever possible. This will put less pressure on raw materials per unit of production than would otherwise be the case. Pinch points will continue to occur wherever sources of key minerals are in the hands of regimes that choose not to share their minerals, until alternative supplies are found and recovered.

Further pressure to reduce consumption will come from environmental considerations. Large volume construction of housing and of transport and communication infrastructure will continue to use raw materials, but pressures will continue to be on lighter, more flexible and more resilient structures that are manufactured. Otherwise the dematerialising of modern life that the IT revolution has brought about will continue providing further relief in the case of scarce resources. The move to mass customisation and increased costs of transport may mean that manufacturing is more evenly distributed round the world than at present.

The general move towards doing more for less with materials, and looking for alternative materials to substitute for those in short supply (e.g. for geopolitical reasons) aligns with UK strengths in academic and industrial R&D. The development of a more systematic dialogue with existing and future potential end users to allow the UK to capture more of the potential value is highly desirable.

2.2 Economic trends

Global supply chain management

Significance in the global economy

Supply chain management is the systematic, strategic coordination of the traditional business functions and the tactics across these business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole (Mentzer et. al. 2001). The advent of sophisticated ERP (Enterprise Resource Planning) systems has made visible to managers many of the transactions in these complex chains, ranging from procurement to material management. Today, companies such as Amazon are offering services whereby you ship your products to their warehouses and they sell and deliver the products for you. GPS, RFID, EPC and other identification technologies are key to this.

Synopsis of manufacturing trends over last 40 years

The global logistics market in 2013 is estimated to be $4 trillion (Van Baren 2012). Between 1995 and 2007, the number of transnational companies more than doubled, from 38,000 to 79,000, and foreign subsidiaries nearly tripled, from 265,000 to 790,000.

Current issues in manufacture

An IBM study involving conversations with 400 supply chain executives revealed that the key issues in supply chains involve:

- Visibility is the top technical challenge - Flooded with more information than ever, supply chain executives still struggle to “see” and act on the right information.
- Cost containment - Rapid, constant change is rocking this traditional area of strength and outstripping supply chain executives’ ability to adapt.
- Risk - CFOs are not the only senior executives urgently concerned about risk; risk management ranks remarkably high on the supply chain agenda as well.
- Customer intimacy - Despite demand-driven mantras, companies are better connected to their suppliers than their customers.
- Globalization - Contrary to initial rationale, globalization has proven to be more about revenue growth than cost savings (Carrol 2010).

Global supply chain management for manufacturing 20 years out

According to the McKinsey report titled "Manufacturing the future: The next era of global growth and innovation", the future is spurred by a rising tide of global uncertainty and business complexity, and is coming sooner than many companies expect (Manyika et. al. 2012). Some of the challenges (turbulent trade and capital flows, for example) represent perennial supply chain worries turbocharged by the recent downturn. Yet other shifts, such as those associated with the developing world’s rising wealth and the emergence of credible suppliers from these markets will have supply chain implications for decades to come. The bottom line for would-be architects of manufacturing and supply chain strategies is a greater risk of making key decisions that become uneconomic as a result of forces beyond their control. First, they are “splintering” their traditional supply chains into smaller, nimbler ones better prepared to manage higher levels of complexity. Second, they are treating their supply chains as hedges against uncertainty by reconfiguring their manufacturing footprints to weather a range of potential outcomes.

IBM released a study on "The Smarter Supply Chain of the Future" (Carrol 2010). It suggested that the future supply chain would be “instrumented, interconnected and intelligent”.

Global supply chain management for manufacturing 20 years beyond that

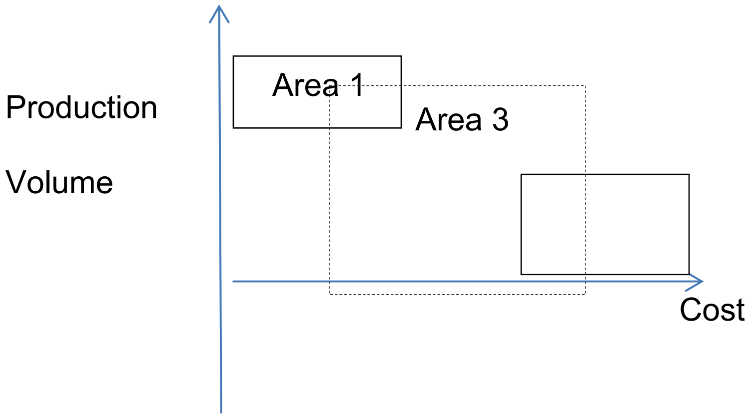
Supply chains will be intelligent and able to deal effectively with risk. The Internet of Things will allow visibility to intensively manage the flow of goods. Information will increasingly be machine-generated—flowing out of sensors, RFID tags, meters, actuators, GPS and more. Inventory will count itself. Containers will detect their contents. Pallets will report in if they end up in the wrong place.

2.3 Sociological trends

Individualisation and personalisation (I&P)

Significance in the global economy

Currently, I&P is a small part of the global economy. This is because it is largely being applied in two areas of the volume versus cost graph below.



Area 1 is "novelty products" that can be personalised on Internet sites such as Shapeways (www.shapeways.com/) and bought for a typical cost of less than £20. In theory, a huge number of people could afford to buy these but currently it is limited to people who are aware of the possibilities and who are willing to spend their time personalising the product. Area 2 is high-value added niche products such as luxury cars or jewellery. The added cost (and profit) of personalisation can be significant but very few people can afford such products. The real economic impact to be made by personalisation is when techniques currently being used in Areas 1 and 2 can be moved into "mainstream products" as shown by Area 3. These are everyday practical products, e.g. vacuum cleaners, that are currently mass produced but which in future could be made through mass customisation. This could be particularly useful in those economies with an ageing society because older people will be expected to be more productive and customised products could help this. Some preliminary research at Loughborough University has shown that customers in a developed economy would be prepared to pay 10% extra for some degree of personalisation. If this could be achieved without a significant increase in manufacturing cost, then the impact on the global economy would be substantial.

Synopsis of manufacturing trends over last 40 years

Over the past 40 years in the developed economies, the decision-making criteria for buying products (especially mid-cost products) have become more complex. At one time cost was the main driver but the buying public now also expects high quality, functional differentiation, usability and now some degree of customisation. Manufacturing and service systems have developed to keep pace with this and to achieve a level of customisation, product configuration has become quite widespread. This is when the customer can choose from a (sometimes wide) range of pre-defined product options to create their own "version" of the product. A good example is an on-line car showroom. In theory, the vast number of permutations that are possible could mean that each customer could have a unique version of the product. In practice, many customers go for the same options. These “product configurators” are becoming more and more commonplace as the web-based technology for setting them up is well established and can be used to drive production planning systems. Some of these configurators have even allowed a degree of personalisation, e.g. Nike ID allowed the customer to put their personalised logo on a pair of running shoes. However, the degree of personalisation is very limited and usually stops short of any change to the product’s shape. Hearing aids and medical implants can be customised rapidly for individual requirements and then produced by Additive Manufacturing (Houses of Parliament 2012).

It has been argued that developed Western economies will need to maintain a competitive advantage against low cost overseas competition. This will require companies to innovate ever more complex products, in ever decreasing volumes, which are either highly personalised to small consumer groups or unique to an individual customer (Materials KTN 2012).

Current issues in manufacture

The main barrier to wider implementation of I&P is the cost of creating personalised components. Additive manufacturing is a very effective method for this but the running costs of high-end machines needed to produce high quality parts is prohibitive in all but the most expensive of products, or products where quality is not critical. Many low-end additive manufacturing machines are appearing on the market which may offer a solution but their build quality and material range are currently lacking. Alternatively, high end machines may become cheaper to run through reduced capital and material cost, and increased rate of throughput. In all likelihood, the overall solution will come from both of these directions and research is needed in both areas. Another barrier to I&P is the current difficulty of capturing customer requirements within the design process, particularly in regard to changing the shape of a product. Current web interfaces and computer aided design (CAD) tools are not suited to this task. Research is needed into web interfaces that can handle geometry manipulation (some do already exist but are rather simplistic) and CAD tools that can be used by the lay person rather than a professional designer. The preferred solution is for web-enabled product personalisation toolkits dedicated to a particular product (or family of products) that will lead the customer through all the personalisation steps in a clear and simple manner. Such toolkits would enable the customer to change the shape of the product within pre-set limits and perhaps according to some aspects their own body shape. Interesting intellectual property questions are raised by this approach since part of the product design will belong to the customer.

I&P for manufacturing 20 years out

In the next 20 years, it is expected that an increasing number of everyday products in developed economies will have some degree of personalisation, ranging from a logo or signature, to individualised ergonomics and aesthetics. This will be achieved through gradual expansion of Areas 1 and 2 into Area 3. This will be facilitated by a combination of modularised assembly and bespoke components that have been created with direct customer input. In theory some of the assembly could be done locally to the customer and essentially “unfinished” products would leave the factory. In terms of personalisation of ergonomics, such an approach would be supported by the use of anatomical data for the individual, which will have been captured at some time through 3D scanning, and then used as the basis for CAD of some of the product components. Additive manufacturing will be a key technology in delivering this although other technologies, such as machining and some types of forming may play a role since they can be programmed to create varying shapes. Challenges will be in determining the most efficient production systems and the most effective business models to achieve maximum profitability.

I&P for manufacturing 20 years beyond that

Beyond 20 years, the nature of personalised manufacture could be changed dramatically by the advent of affordable, high-quality, multi-material additive manufacturing (or more likely hybrid manufacturing and assembly) machines. These could create entire products to an individual's specification and could be located at dispersed locations rather than at a single factory site. There could also be a move towards incorporating local materials into the product. Such localised manufacturing would have a substantial effect on the transportation of goods around the world and hence on the global carbon footprint.

2.4 Environmental trends

Sustainability

(Note: energy is dealt with separately).

Significance in the global economy

Various methods of ecological foot-printing suggest that the developed nations are living in an unsustainable manner, to the extent that if everyone lived to the same standard in a regime of global equity, many of the basic resources of minerals, and access to clean water and fresh foods would not endure for long. For humans in social systems or ecosystems, sustainability is the long-term maintenance of responsibility, which has environmental, economic, and social dimensions, and encompasses the concept of stewardship, the responsible management of resource use (Miller and Spoolman 2011).

Synopsis of manufacturing trends over last 40 years

Sustainable consumption was not an issue more than 40 years ago. It is 50 years since Rachel Carson's 'Silent Spring' and over 40 since the 1970 Club of Rome report on the world's supplies of minerals. These gave rise to the modern environmental movement which has grown ever since and has focussed on the increase in sustainable living. Our concern here is with the manufacture with a minimum stress to the supplies of resources. Thermodynamics indicates that we cannot get anything for free, so all manufacture consumes resources, but one seeks to reduce this consumption to a minimum. Efficiency of manufacture is one driver to reduce resources, but the environmental movement has led politicians to privilege sustainability higher than would be implied by economics alone. In real time there is a shakeout in many of the renewable technologies because of the dismal economics of operation.

The increasing level of recycling of domestic waste is one of the clearest indications of the societal concern to be more sustainable. This increased the possibility of reusing materials and reducing the mass of material taken to landfill. The comparable recycling in industry is partly motivated by savings, but also imposed by local ordinances and national laws which vary considerably by location and in some cases is the reason for moving plants. For example, higher energy bills to subsidize alternative sources of energy (done to reduce climate change) have driven two of the three UK aluminium smelters to move offshore.

Current issues in manufacture

Of all sectors of the economy, the construction industry is one that still generates waste which could be greatly reduced if a more aggressive approach was taken to introduce new methods of construction. There is very little standardisation of buildings, with variety being seen as highly desirable by society, except perhaps in China where volume of new build is the priority: standard parts could be manufactured to order with little waste compared with oversized blocks or sheets of material cut to size at the building site. The move towards off-site modular construction may reduce the amount of waste.

Current issues include the desire for simple materials in simple combinations (for ease of recycling) versus complex combinations for reducing energy use (e.g. lightweight vehicles). The analysis of the life-cycle of a product to reduce whole-life cost and consumption is also an issue. The original Xerox machine was for hire, not purchase, and was designed to enable easy recycling. This model could return in a more pervasive manner, by regulation if thought desirable.

Sustainable food production will require some changes in horticultural techniques, such as less use of water and of artificial fertiliser, and more small-scale local production to reduce energy consumption. That said, flowers grown in Kenya and air-freighted to Europe have a lower foot-print than the same flowers grown in European hothouses. Carbon budgeting in the cause of sustainability is throwing up a number of such anomalies.

From a practical business point of view, in his still-insightful 1999 book (Davis 1999); Davis shows how it makes good business sense to manufacture without waste. In parallel to the concerns of design for manufacture, design for minimum waste is also considered desirable.

The reuse of reinforced steel as used in buildings without resmelting is still at an embryonic stage, but this is likely to grow as confidence and experience is gained.

A recent study compares four manufacturing strategies of increasing sustainability from waste minimisation through materials efficiency, and overall resource efficiency to eco-efficiency, covering the definition, scope, practicality and compatibility of the strategies, showing the last to be the hardest to implement but likely to have the greatest impact (Abdul Rashid et. al. 2008). Indeed there are many contemporary studies of adding sustainability factors to modern manufacturing (Cannata and Taisch 2010). These studies lack hard numbers that would follow from a more concrete analysis of the engineering issues, which in turn would offer targets for companies and the regulators. The present use of CO^2 targets in the EU is a blunt target that is actually making matters much worse in the energy sector with unsustainable subsidies having to be cut leaving stranded assets not able to be maintained in operation. It is ironical that the US has done more in the last decade to reduce carbon emissions while being steadfastly outside the Kyoto protocol.

Biodegradability has become an important issue with the increased use of plastics. For some applications, such as buried pipelines, the longevity of plastics is important, while in other areas, such as maritime waste, where plastics last from 10-20 years for bags, 100 years for sift plastics and an estimated 400 years for hard plastics, it is considered a nuisance, needing to be engineered away (C-More 2013). The emphasis on the journey that is increased sustainability has been described for the UK plastic sector (Law 2013). And a pathway for moving towards a zero carbon manufacturing economy in the UK has been outlined (Smith School of Enterprise and the Environment 2012). It is this rich variety of issues around waste resilience, energy efficiency etc. that will help focus decisions on the manufacture of future products, and the competitive edge that can be achieved.

Sustainability for manufacturing 20 years out

By 2050, the sustainability issue will be twice as old as it is now, and the implementation is likely to be that much more sophisticated. There are more radical suggestions which state that a “desirable and acceptable future” urgently calls for a shift from economic to sustainable development (Jovane et. al. 2008). A group of young people in New Zealand have developed a vision (Sustainable Business Council (NZ) 2012) for sustainability in that country, which mutatis mutandis is a starting point for other locations. There are no explicit actions on manufacturing, but rather industry has adopted all the considerations listed above and are continuously making improvements on them. Indeed there is little of real vision indicative of game-changing discontinuities is these studies.

The largest volumes of materials in manufacture are used for buildings, infrastructure and transport. Incremental improvements in product design, materials substitution, and design for re-use will have an impact on these large volumes of materials, and any UK-specific intellectual property here will be a prime export commodity, and through aid programmes, provide a means by which developing countries can bypass the more wasteful materials consumption stages that the West has passed through. In the case of higher-added value manufacturing, the volumes of material are smaller, and greener manufacturing is possible.

3. Technologies

3.1 Additive manufacturing

Significance in the global economy

AM (or 3D Printing as often referred to in the press) produces parts by adding layers of material to build up an object. In most cases the material is produced in thin flat layers but there have been attempts to add material in voxels. It was initially developed in the late 1980's/early 90's as a group of processes to produce prototypes quickly for the product development world. Hence, it was originally known as Rapid Prototyping. In the early to mid-90's there was great interest to use these processes to manufacture tools for injection moulding. However, with the advent of High Speed Machining and better software for programming using AM to manufacture tools became uncompetitive in most applications. In 1997 it was proposed that AM could economically manufacture end-use parts in lots up to 6,000 (Dickens and Keane 1997). Since then much attention has been devoted to transforming these processes from prototyping to manufacturing. The largest market for these processes remains in product development but manufacturing end-use parts is growing quickly and in 2012 accounted for 24% of parts and services (Wohlers 2012). In 2010, the market for AM products and services was $1.325b, and $1.9b the following year. This market could grow to $100b by 2020 (Materials KTN 2012). Although the AM market is still relatively small it is the cornerstone for product development in converting Computer Aided Designs to prototype parts. Its importance in the manufacturing arena will also continue to grow at a rapid rate (currently about 26% per annum).

Synopsis of manufacturing trends over last 40 years

Until the 1980's the rate of change for products was relatively slow with new models appearing after several years. However, with a trend for new models to be introduced ever more frequently, by the end of the 1990's it was common for a new model to appear every year, especially in the computing, mobile phone and consumer products market. This increase in the rate of change placed great pressure on companies to manufacture prototypes more quickly. Before Rapid Prototyping was introduced it was common for large complex plastic parts such as a television housing to take 6 to 12 months to make and cost several hundred thousand pounds. Some companies avoided prototyping and went directly to production tooling to manufacture parts. This often resulted in expensive tooling changes and delayed product introduction. The advent of Rapid Prototyping suddenly meant that a large complex part could be produced in days rather than months. There has been a steady decline in product lifetimes, an increase in the number of variants and reduction in production quantities. This means production tooling is more difficult to justify and increases the risk of investing in tools that are difficult or impossible to change. Therefore, using a tool free process such as AM to manufacture parts is very attractive. This is further driven by demand for customised manufacturing. More recently companies have explored the ability of AM to manufacture complex geometries that could not be made by any other process. These parts have great potential to reduce the weight of products, especially in sectors such as aerospace, automotive and consumer products.

Current issues in manufacture

A range of problems exist before AM can be used for manufacturing on a larger scale (Shipp et. al. 2012). AM is suitable for small production runs, small parts, high value products and products with complex geometry. Economic quantities depend on the combination of these factors. For example, large complex plastic parts (0.74 kg) are economic for lots of about 280 to 300 whereas small simple parts (3.6g) are economic up to lots of 6,000 (Hopkinson 2006). However, for metals most AM applications are still at the validation stage between TRL3 and TRL5 (Hague et. al. 2012).

There is a variety of issues holding back industry from wide scale use of this technology:

- Speed – Processes add material at a very slow rate and conventional processes are 1 or 2 orders of magnitude faster. Part of the problem is that current processes were designed for prototyping where throughput of material was less of an issue.
- Repeatability – AM machines have little process prediction or closed loop feedback. Therefore, without improved repeatability it is difficult to become a reliable process.
- Poor materials data – there is little comprehensive information on material properties because these processes are still in their infancy compared to conventional processes. The establishment of a standards body (ASTM International – F42) will greatly help with uniform testing standards.
- Lack of trained designers/engineers – A major benefit of AM is in producing complex geometries. However, we do not have a body of designers that can think in a new way to exploit this. There is also a lack of trained engineers and technicians to optimise the processes and run them. AM is likely to create opportunities for designers, engineers, technicians, software programmers and other such occupations, but likely to reduce production jobs, which will have implications for the UK's skill mix, and may exacerbate labour market polarisation (Sissons and Thompson 2012).
- Supports – In many systems overhanging features need a material to act as a support as with scaffolding when erecting buildings. Supports may be the same material as the part or completely different. The processes were initially used for prototyping parts that would be made by processes such as injection moulding. They were not very complex and so removal of supports was relatively easy. However, as parts become more complex the support removal becomes more difficult or impossible.
- Design Software – Existing CAD software works well for parts made by conventional processes. However, it does not work well for the complex geometries (e.g. internal lattices and surface textures) that can be made by AM. Problems exist with geometry optimisation and representation of mixed or graded materials etc.
- Business Models – AM enables lots sizes of one, customised products and remote manufacturing. This will require companies to design business in a very different way to exploit this technology.
- Electro-Mechanical Systems Integration - Though layer-based design allows direct build of mechanisms, the majority of applications remain focused on static parts; mechanism design integrated with sensing, actuation, and computing (control elements) demands new paradigms in design, simulation, and fabrication. Future visions of rapid manufactured mass customized robotic devices will be heavily reliant on such advances.

AM for manufacturing 20 years out

There will be a great effort over the next 20 years to overcome the problems above and AM will become a mainstream manufacturing process that complements or displaces many existing processes to a significant extent. There will be extensive work to research and develop processes that produce parts in multiple materials. There is currently a great deal of interest in AM within the domestic setting with simple machines now costing less than £1k. Most sectors will be using AM ranging from the medical industry making replacement organs (of particular benefit to an ageing population) to the aerospace sector where a high proportion of the components will be produced by these processes. We will see completely new business models based on AM.

AM for manufacturing 20 years beyond that

Currently most processes convert material point by point and so this leads to low material throughput. There is some processing of liquid resin materials by area using Digital Micromirror Devices. However, the energy that can be transmitted by these devices is low so other techniques will be required to process metals by area. In the long term, material will be processed on a volume basis and may use techniques such as Directed Self Assembly (Ding et. al. 2009).

AM for UK manufacturing

The Technology Readiness Level of AM largely depends on whether it is used for prototyping or end-use parts and whether it is for single material or multi-material parts. For prototyping of single materials this is now well established commercially throughout the world and so it is at TRL 9. For end use of single material plastic parts it is almost fully established but at TRL 7 the UK is behind the USA at TRL9. However for end use parts in a single metal the UK TRL of 5 is slightly ahead of other countries at TRL 4. The big difference is in multiple/graded materials where it is at TRL 7 at home and overseas for prototyping but for end use parts it is still at TRL 1 or 2.

When considering this technology on a 10 point scale the importance of AM for the future success and competitiveness of the UK in manufacturing activities over the medium and long-term is high at 9 or 10 for prototyping or end-use. AM is initially being used more heavily in aerospace and medical but moving to all sectors such as consumer goods, sports products, orthotics, prosthetics, aero interiors and hearing aids. AM has high potential for developing competitive future products (9-10), for achieving on-going competitive advantage for Cost (8-10), Quality (7-9) and Delivery (9-10). It is interesting to note that Nike require suppliers to have an Additive Manufacturing machine so that designs can be transferred directly to reduce product development time and increase responsiveness.

In terms of research and development for single material prototyping the research work has largely been completed. There will be new materials and process becoming commercial with help of TSB projects.

In the longer term the emphasis will be on end use products and multi-material AM in particular where there is a need for research to investigate design methodology, design optimisation processes, CAD representation, additive processes and materials. In the business area there is a need for research into business models. The UK has a leading position in current metallic AM R&D with companies such as EADS having well developed programs. The UK leads EU FP7 research in this area. We also have Renishaw as a machine tool developer.

For application of knowhow in prototyping there is still some need for training on a national basis to update older engineers and designers to transfer knowledge of these processes. We do not have intelligent process selection tools to decide which ones to use. For end use parts there is still little knowledge in industry as to how to maximise the benefit of these processes. A national programme of training is required that covers all education ranges from schools to PhD. This will become even more pressing for multi-material systems.

In the short to medium term to promote indigenous growth of AM industry in the UK there could be more coordination to exploit the considerable amount of research nationally in this area. However, there is only one manufacturer of machines and few suppliers of materials. There could be a BIS programme to promote these areas plus software tools. A recent TSB call will be investigating design and business opportunities. New processes are currently going overseas. There needs to be a mechanism to ensure they stay in the UK.

To incentivise world leading players to establish their bases in the UK there could be initiatives which would partner them to other companies or universities here when they employ a minimum number of people in the UK. This would require evidence of a much stronger take up of the technology nationally.

The main barrier to exploiting this technology is a lack of knowledge within industry. There has been a considerable effort by a number of organisations over the last 20 years but this has not been enough. A coordinated national effort is required. At present there is little if any training in the area. A well thought out coordinated action is required. There is still a need for better materials that are closer to production materials. There are other barriers to the application of this technology, most notably a lack of process economics and materials science, but also the lack of design software tools, analysis and modelling tools that will overtime restrict take-up.

The common barriers are a lack of training and few UK suppliers of machines, materials and software. Government options to remove barriers the barriers are:

- A national programme of training (schools to HE).
- Incentives for UK companies to be suppliers of machines, materials and software.
- Incentives for overseas companies to establish in the UK

The main barrier in most countries is the lack of inventiveness for new processes, materials and applications. Some countries suffer the same barriers as the UK such as France and Italy. Countries with more small companies such as France and Italy also suffer because they have not afforded these processes in the past. Imported manufacturing companies have little need for RP so we need to stimulate more design in the UK.

Other countries methods to remove barriers include:

- Germany has a well-coordinated action amongst the Fraunhofer institutes to promote this area.
- The USA has recently announced the establishment of a National Additive Manufacturing Innovation Institute with $30m in federal funding.
- Australia is reviewing investment in materials development to supply this sector.

3.2 Artificial intelligence and machine learning (AI&ML)

Significance in the global economy

Artificial intelligence has been embedded in products in the area of medical diagnosis, automated stock trading, autonomous vehicles and robotics. It has also been applied to the operations of manufacturing processes and to the marketing and selling of products. Perhaps its biggest impact will be seen in the management and operation of large scale infrastructures, such as Smart Grid and Smart City.

Natural language processing allows machines to "understand" a wide range of voice and text commands. AI based systems help in market monitoring, analysis, planning and automated trading of stocks. Machine learning has been applied to finding the precursors of heart attacks. Google's fleet of robotic Toyota Priuses has now logged more than 300,000 kilometres, driving in city traffic, busy highways, and mountainous roads with only occasional human intervention. Apple's Siri and Google Now are already able to act as a smart assistant, booking dinner reservations, airline tickets etc. Autonomous drones are capable of surveillance and autonomous cars have demonstrated their ability to navigate urban environments. Google's automatic completion of queries guides users through complex requests for data.

Synopsis of manufacturing trends over last 40 years

IBM’s Deep Blue beat Garry Kasparov in 1997 using 510 processors. But by 2006, the focus in chess playing algorithms had switched to software, with the best programs running on a dual processor computer. IBM’s Watson used 2,880 processing cores to win Jeopardy in 2011. Fuzzy logic has been applied to vehicle stability control and electronic stability.

Some of the main techniques include: fuzzy logic, game theory, expert systems, spatial reasoning, neural networks, support vector machines, hidden Markov models etc.

Current issues in manufacture

AI-based technologies have been used in products such as missile systems, heads-up-displays, and route finding. In manufacturing processes it has been used for automating CAD layout of wiring and piping, in smart control systems and in machine learning about component lifetimes and pre-cursors to failure. AI has also made the transition to the home with automated vacuum cleaners and pet robots.

AI&ML for manufacturing 20 years out

There are a number of challenges to be tackled in the next 20 years (Selman et. al. 1996):

- Adaptive computing mimics biological systems which can adapt to new environments. Currently our programs are very brittle, and a program compiled for one architecture cannot run on another. Can we build a program that can install itself and run itself on an unknown architecture?
- Robust computing - Can we make computer programs more robust and tolerant of faults.
- Biological Learning - Recent work with evolutionary system has produced some tantalizing spectacular results, e.g., (Sims 1994). Can newer models provide us with new computational tools, and will they lead to new insights to challenge the learning capabilities that we see in biological learning?
- Complex Game Playing - Can we build a program that plays chess in the way that a human plays?
- Natural Language Processing - All of the competitive speech understanding systems today use hidden Markov models. Can we build a speech understanding system that is based on very different principles?
- Evolutionary Computing - Can we build a system by evolution that is better at a non-trivial task than anything that has been built by hand?

AI&ML for manufacturing 20 years beyond that

There are some AI Grand Challenges (Selman et. al. 1996) such as - Can we annotate 1000 hours of digital video in one hour? Artificial intelligence will create more realistic and engaging game play. Rather than relying solely on pre-programmed interactions, AI can allow games to adapt to their player's mid-game. While there are some technologies being employed that simulate artificial intelligence in video games, true AI hasn't yet been achieved. Newer technologies, like dynamic scripting, could bring game AI to a new level, leading to more realistic game play. NASA and other world space agencies are actively looking into artificial intelligence for controlling probes that might explore star systems outside our own.

AI&ML for UK manufacturing

The Technology Readiness Level of AI&ML in the UK (TRL 6) is only slightly lower than abroad (TRL 7).

When considering this technology on a 10 point scale the importance of AI&ML for the future success and competitiveness of the UK in manufacturing activities over the medium and long-term is rated as very high (10). AI&ML is already in autonomous vehicles but quickly moving to all areas of control. AI&ML is very important for developing competitive future products (10) but seen as less important for achieving on-going competitive advantage for Cost (7), Quality (7) and Delivery (7).

In Research & Development there are many "grand challenges" yet to be achieved but some of these are in game playing applied to education or natural language processing. The main repository of know-how for AI&ML is within the universities and its penetration into industry is limited. The main barrier which applies in all countries is a lack of reliability of AI and of software in general. This could be overcome with research into robust software development.

3.3 Big Data

Significance in the global economy

In manufacturing the drive is to optimize design, production and product lifecycles while minimizing energy and resource use. Big Data promises the ability to measure every vibration of a motor, every joule of energy consumed, every click of a CAD user - and translating it into useful, actionable intelligence. The enablers of this revolution are the development of sensors to gather the data, the networks to transmit the data and the computing ability to store and analyze the data.

Big Data analytics now permeates the worlds of commerce, finance, and government. Credit card companies monitor millions of transactions to uncover fraud; financial analysts' crunch market data to identify investment opportunities; and the Department of Homeland Security tracks Internet and phone traffic to forecast terrorist activity. In medicine big data is influencing the areas of genomics-driven research (genotyping, gene expression, and next-generation sequencing data); and at the payer-provider end, electronic medical records, pharmacy prescription information, insurance records. "The Fourth Paradigm" lays out the significance of Big Data for scientific research. It describes the potential for large data sets to revolutionize scientific discovery (Hey et al, 2009). They believe we are at a stage of development that is analogous to when the printing press was invented. A new report from analyst firm Gartner forecasts that IT organizations will spend $232 billion (US) on hardware, software and services related to Big Data through 2016 (Beyer 2012).

Synopsis of trends

Starting in 1996 Google (officially registered in September 1997) built a distributed file system called Google File System and developed a framework called MapReduce for running algorithms on hundreds of millions of web pages. By 2010, Facebook had the largest Hadoop cluster in the world, with over 20 PB of storage, called Hadoop Distributed File System (HDFS). By March 2011, the cluster had grown to 30 PB — around 2,000 times the size of the British Library! Facebook has around 1 billion users worldwide and hosts 140 billion photos out of 3.5 trillion estimate total in history. This year 20% of all the photos taken will be uploaded to their site.

Current issues in manufacture

Companies in the 90's realized that by placing most of their operational data in Enterprise Resource Planning Systems (ERP), they could get visibility into their operations. Their critical data was on the order of a few Terabytes and was typically held in a single or small cluster of machines. These systems allowed companies to optimize their operations and compete more effectively against their competition. At around the same time Google, using a different approach, demonstrated an ability to rank billions of Web pages and do sub-second query matching using a distributed file system. To do this they used thousands of "off the shelf" machines and developed fault tolerant algorithms. The concept of the Internet of Things and the rise of URL addressable sensors and devices such as smart phones, RFID readers and SCADA units allowed companies to gather data in almost real time, streaming large quantities of data into their servers. The potential for fine grained real-time visibility into their operations encouraged companies to move away from traditional relational databases and to move towards Google's distributed file systems. At almost the same time social networking sites such as Facebook, Twitter and Youtube allowed millions of users to upload content to distributed servers on the Web. Surprisingly, cell phone technology combined with these social networking sites has triggered information interchanges that some believe have been destabilizing forces in societies, such as in the Middle East (Giglio 2011). Today, "sensemaking" of Big Data is seen as the Holy Grail for security forces, for corporations and for science.

Big Data for manufacturing 20 years out

As described in the Fourth Paradigm we are seeing the evolution of two branches of every discipline (Hey et al. 2009). If you look at ecology, there is now both computational ecology, which is to do with simulating ecologies, and eco-informatics, which is to do with collecting and analysing ecological information. Similarly, there is bioinformatics, which collects and analyses information from many different experiments, and there is computational biology, which simulates how biological systems work and the metabolic pathways or the behaviour of a cell or the way a protein is built." In MIT the new field of Connection Science and Engineering is being launched to understand the relationships between entities in complex systems like the World Wide Web.

Big Data for UK manufacturing

The Technology Readiness Level for Big Data is the same in the UK and abroad (TRL 8) and is seen as very important (10) for the future success and competitiveness of the UK in manufacturing activities over the medium and long-term. Big Data is being used in several sectors such as Business, Government and Military intelligence in applications such as ‘smart cities’.

When considering this technology on a 10 point scale Big Data is seen as very important (10) for developing competitive future products but slightly less so for achieving on-going competitive advantage for Cost (8), Quality (9) and Delivery (9).

In research and development there is a need to investigate new algorithms in parallel computation and hardware such as in very large memory machines and there is a good basis within the UK universities to exploit this area. The main barriers affecting the future uptake and commercialisation of Big Data is investment and a lack of skilled professionals and the Cross-disciplinary nature of the problem. The government options to remove barriers would be to launch major initiatives in industry, government and universities. The barriers in other countries are similar where there is sponsored research and government initiatives that try to overcome them.

3.4 Biotechnology and medical technology

Significance in the global economy

Most developed economies are struggling with an ageing population. With increasing life expectation comes the eventual need to raise (or abolish) retirement ages and keep the population fit, healthy and productive. There is therefore a 2-way economic impact; the development and manufacture of biomedical technology as well as the economics of having a more productive nation. Biotechnology also relates to the global economy through the treatment of diseases as well as increasing the efficiency of plant growth in difficult climates and conditions. With this we can expect a healthy population that has adequate supplies of food at a sustainable level. Achieving this is obviously a monumental task that requires heavy investment at both the developmental and implementation stages.

Biotechnology and medical technology is improving in leaps and bounds. One can define biotechnology as anything that exploits or enhances biological products (both plant and animal) and medical technology as that which treats (mainly human) medical conditions. The human body contains a multitude of interacting complex biomechanical and biochemical systems which, inevitably, require replacement and/or regeneration. As individuals age, a host of physical issues become more acute, as does the need for physical, sensory and sometimes cognitive assistance in a variety of daily activities and tasks. This demand for tissue/organ replacement will rapidly drive up global healthcare costs in the next decade. The economic impact due to lost productivity and loss of human quality of life will be great. To address this demand, the worldwide global market for engineered tissue systems is projected to increase to $27B by 2018 from $6.6B in 2008. The market segment spans all areas of tissue engineering therapeutics including Orthopaedics, Integumentary, Oncology, Cardiology, Dental and Neurology (Industry Experts 2012). While this projected market demand is only for therapeutic purposes alone, there is a significant potential for engineered tissue systems to be applied towards theragnostics products, in vitro human tissue models, in vitro meat, in vitro leather and tissue based biosensors that can significantly increase market size by several fold. The need for high throughput testing of vaccines and pharmaceutical drugs alone could drive up great demand by the pharmaceutical/cosmetic industry for engineered tissue systems that replicate human biology. The next decade will see great pressure on the traditional means of leather and meat production which could lead to further demand for engineered leather and meat products. While the potential market size is enticing, true potential of Engineered Tissue/Organ Manufacturing (ETOM) can only be achieved by the development of scale-up production and economical manufacturing processes that can help translate laboratory scale process to large scale industrial level current good manufacturing practice (cGMP) production. This requires development of bio-fabrication processes that are reproducible, robust, well controlled, personalized and user friendly to help broaden the distribution of engineered tissue products for end use in patients and within R&D laboratories. Successes through tissue manufacturing processes can lead to further financial investment in technologies that prime commercial level personalized organ manufacturing.

Synopsis of manufacturing trends over last 40 years

The United Nations Convention on Biological Diversity defines 'biotechnology' as: "Any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use." 40 years ago we would normally have looked on this as experimental models that were based on largely misunderstood principles. Probably most uses would have been in food manufacturing, like the use of yeasts in baking and brewing or enzymes used in dairy products like cheese and yoghurt. Although these have been used for centuries, the careful regulation and control of conditions for reliable and repeatable use is probably only 40 or so years old. We would also be seeing the start of the development of antibiotics beyond penicillin about that time as well.

Most of the growth of this industry sector has in fact been over the last 40 years. Genetics started in the early 70s, as did the use of organisms in production of petrochemicals, plastics and fuels from biomass. In general all this required biochemical plant technology that involved heavy investment and expertise. Many manufacturing plants could be considered industrial scale laboratory-style arrangements. Whilst this is still the most common way of looking at biotechnology manufacture, there are also a huge number of small scale labs that are working on very specific biotechnology areas. For example, a company may have specific expertise in producing protein or bioactive molecular attachment to an implantable medical device.

Medical technology is mainly in the hands of a small number of multinational companies. This is particularly true of drug technology. Medical devices for implantation are also controlled by a different group of companies, but there is some indication that in Europe in particular this is changing. For example, the use of Additive Manufacture for custom implants is becoming a popular approach due to the added benefits of faster and more efficient surgical procedures as well as improved quality of life to the patient.

The harbinger to developing engineered tissue/organ manufacturing perhaps arises from the rapid advancements made in medical device industry, particularly personalized metal based implants (orthopaedic and dental), composites implants (vascular stents, synthetic neural tubes) and polymer based implants (breast, face, and skin). Over the last 40 years, manufacturing processes for producing implants have been vastly aided by advancements made in computing, non-invasive imaging and materials research. Implants are lasting longer, more biocompatible with reduced wear and inflammatory responses, they are customized to meet physiological requirements and perhaps are ‘smarter’ through embedded sensors to ensure corrective procedures are taken before implant failure.

While medical implants can restore some function, they still do not serve to be a complete replacement to the human bodies’ own tissue and organs. Advancements made in biomaterials research, medical imaging including CT/MRI/PET/US modalities for 3D reconstruction, biofabrication processes aided by additive manufacturing, sensors, micro and nanofabrication have certainly advanced tissue engineered products albeit at the laboratory scale level. Recent progress has been made in automating laboratory procedures in tissue scaffold and cell culture production through the use of digitally enabled fabrication technologies, robotic manipulators and computer controlled bioreactors. This activity must further progress to ensure consistent manufacturing practice approaches which therefore lead to economically acceptable engineered tissue/organ products.

Current issues in manufacture

The key issues in manufacturing are:

- Scale - As mentioned above, many of these technologies are in the hands of a small number of large companies. This is partly because of the huge plant and infrastructure that is required to realise biotechnology and medical products. This makes it extremely difficult for small enterprises to get involved. Whilst there are numerous start-up companies spawned from research centres, their products are often not viable unless there is manufacturing capability at a sufficiently large scale.
- Decentralisation - Or rather lack of it. Related to the above, large organisations appear to be dictating most of the development of bio and medical technologies. There is a problem related to distribution of this technology, particularly to poorer nations but also to countries that have different health and safety regulations or medical treatment regimes (for example insurance-based compared to national health schemes). Products developed in the USA for example will have to be modified to suit another nation's requirements. This has led to satellite companies being established in other countries but an American company's factory based in the UK may still not be able to produce drugs for other parts of Europe for example.
- Regulation and approvals - The Food and Drug Administration sets the standard for product development in this area. These are necessarily stringent, but it appears that the developmental time and process is inordinately long and getting longer as new regulations come into practice. Further, seeking approval to carry out experiments is becoming more and more difficult. Ethical advisory boards and social pressure groups restrict the type, length and number of experiments that can be carried out. This is particularly so for Europe and the USA. Asian research institutes have much more relaxed approval processes and generally do not suffer significantly from social pressure groups. This may also become the case in Africa and South America as their research institutes move into these fields.
- Speed and cost of development - Most new bio and medical technology starts with research centres. They are generally well funded for the carrying out of preliminary trials that indicate product viability. Such trials are also quite well regulated and results can easily be verified independently. However, funding often comes in stages and further funding is dependent on previous results. Getting to large-scale trials becomes a lengthy and expensive process, particularly if the research centre wishes to remain independent of the large companies. For example, new materials that have been identified for implantation are tantalum and magnesium alloys. Concern over existing implantable alloys like titanium, cobalt chromium and even stainless steel means that these new materials will take a very long time before full approval.
- Transfer to SMEs - There is some indication that some medical technologies and processes have become streamlined sufficiently to become applicable to smaller companies. For example, construction of customised titanium medical implants can be carried out using Additive Manufacturing equipment in a small factory in Europe. Since titanium is already FDA approved, these products can be accepted without much further medical institutional or patient approval. It may also be that some specialised bacterial strains for digesting sewage waste have been developed by small companies to aid in treatment, recycling and biogas production. Medical

devices are routinely made by small companies since they do not interact directly with the biochemical processes.

- Intellectual property - Much of the above is driven by the fact that there is potentially a great amount of money to be made from the correct combination of molecules with external agents. It is typical for Chemistry and Chemical Engineering researchers to routinely patent any new molecule that has been designed or synthesised. Many of these patents have little or no practical value at the time of filing and the associated claims are deliberately vague. There are therefore a bewildering number of patents making it difficult to identify which ones are truly useful. Information regarding these chemicals is difficult to obtain and there is a tendency to prevent disclosure until patent procedures are filed.
- The lack of reliable, consistent and scalable manufacturing processes for medical products presents a challenge to the commercialization of laboratory proven technologies. Several laboratory proven technologies exist for replacement substitutes for internal tissue/organs that include heart valves, bone, kidney, liver, nerves and cartilage but this has not translated to cost effective viable large scale bio-production technologies. The issues include:
- Insufficient Cell Sources, Slow Cell Proliferation Rate and Lack of Constructs that Mimic In-vivo Physiology - No matter how much automation is achieved, the proliferation rate of cells cannot be normally manipulated to achieve much faster cell proliferation rates. In addition, cell sources for necessary therapeutic function can be a limitation.
- Insufficient Knowledge in Cell Biology to Understand Tissue Regeneration - There is much work to be done to understand the tissue regeneration mechanism. More advanced tools must be made available to biologists to rapidly aid in studying this process.
- Lack of Integrative Cell/Tissue/Organ Functional Computer Models - Computer models are not available to predict the role that external parameters can have on cellular response and behaviour. New multi-scale and predictive models must be developed to explore several what-if analyses before expensive experimentation.
- Lack of Material Standards and Process Standardization Protocols - Viable large scale production can only be made possible when source biomaterials and unit process operations are standardized and well characterized. Variation and error sources must be minimized to gain regulatory agency approval.
- Not Enough know-how on how to Measure and Control Automated Tissue Manufacturing Facilities - Developing in-process metrology and adequate control thereof will be key to further developing manufacturing processes that involve ‘living’ matter.
- Storage and Transportation Logistics for Living products to End Use Site - questions on how to effectively store and transport living products must be addressed for eventual use.
- Poor Availability of Hardware Devices for Tissue Manufacturing Research - Every lab has to build its own machine for bio-fabrication research. Expensive clean rooms must be built that prevents widespread research into further developing this area.

Biotechnology and medical technology for manufacturing 20 years out

Biotechnology manufacture is still likely to be mostly large-scale. However the range of products is likely to be significantly increased. This will have an impact on manufacturing. Large-scale and highly expensive plant technology is still going to be the way in which products are manufactured. However, these factories must be much more versatile, involving many more products than previously. Probably there will become a greater need for manpower in this field although many processes will be highly automated and generic. There will be a much better understanding of biotechnology by this time and development of biotech agents to treat widespread issues like crop growth, malaria and other insect-borne diseases.

In the field of medical technology, we can expect widespread use of robotically assisted surgery and other automated treatment processes. Self-diagnosis will be more common and so reliance on centralised medical treatment facilities will be reduced. Medical technology will be much more patient specific. Understanding the medical conditions of individuals will be much more effective. Further, the production of customised implants will be commonplace. Medical scanning technology will primarily be 3D and use of materials like titanium with appropriate bio-coatings can be used to routinely treat bone trauma and bone degenerative conditions like osteoporosis and cancer.

There will be renewed effort to address some of the challenges above to ensure viable manufacturing of tissue replacement substitutes for Bone, Neural Conduit Tubes, Cartilage and Blood Vessels. Several products are in the clinical testing pipeline. In the next 5-10 years, we will see some of this technology entering widespread patient utilization. We will also see large scale production of stem cells, advanced three-dimensional multi-material scaffolds and in vitro models systems as new advanced tools to study tissue regeneration and pharmaceutical drug screening. We will also see development of complimentary technology that supports the production of living tissue – advanced multi-modal sensors, in-situ imaging, rapid in-line analysis of culture media and predictive data analytics to ensure controlled production processes. We will also see the next generation of tissue manufacturing facilities that adhere to cGMP standards while meeting regulatory agency requirements.

Biotechnology and medical technology for manufacturing 40 years out

There will be widespread and pervasive use of customised biotech agents. With the massive increase in understanding we can expect such agents to be available from large and small developers and retailers. Biotechnology will be commonplace in everyday activities (e.g. flavour enhancement in foodstuffs, home waste recycling, cleaning products, etc.) and it should even be possible to tailor or customise a bioactive product to provide a specific effect or result.

Merging of biotech and medicine (e.g. wound cleaning, anti-aging creams assisting cell regeneration, etc.) will probably be in both the preventative and treatment fields.

In the previous section, we refer mainly to widespread use of biocompatible materials within the organ replacement field. This could be artificial hearts, kidneys, lungs, bones, etc. Within a 40 year period we can expect tissue engineering to have developed sufficiently to grow actual replacement parts using cell printing technology.

One can also envisage that fully automated surgery, perhaps with the assistance of nano-robotics to carry out procedures from within the body in a minimally invasive approach, could be possible by this time.

Commercial success obtained in near term applications of engineered tissue over the next 20 years will lead to further investment into technology that will help lead to personalized organ replacement – kidney, liver, pancreas, heart patch from cell sources of the patient. Beyond therapeutics, we will also see adoption of engineered tissue for applications in biological and chemical sensing. Perhaps also technology that leads to the production of in-vitro meat that can help sustain global food demands. In the long term, new development in biomaterials, a better understanding in multi-scale cell and tissue interaction and newer manufacturing processes that can replicate in-vivo physiology will lay the groundwork for personalized organ manufacturing.

Biotechnology and medical technology for UK manufacturing

The Technology Readiness Level of Biotechnology and medical technology in the UK and abroad varies greatly depending on the particular aspect concerned where some areas are at TRL 9 whereas ETOM is at low TRL levels (2).

When considering this technology on a 10 point scale the importance of Biotechnology and medical technology is seen as very high (10) for the future success and competitiveness of the UK in manufacturing activities over the medium and long-term.

The Biotechnology and medical technology area has connections across healthcare, defence and food. Biotechnology and medical technology is very important (10) for developing competitive future products and for achieving ongoing competitive advantage for Cost (10), Quality (10) but less so for Delivery (6).

There is a great need for further research and development in many aspects of Biotechnology and medical technology and there will need to be a great deal of training in both engineering and life-sciences. A new breed of Masters' and Ph.D. biomedical engineers will be needed initially. The Biotechnology and medical technology sector in the UK is strong but a long term strategy will be required to ensure indigenous growth and import of world leading players.

The main barrier to exploiting Biotechnology and medical technology has been a tendency to one-dimensionality in research funding that has approached from a clinical perspective. If issues related to manufacturing are considered early on in the process, investment can be channelled to only those technologies that are economically viable. There is a lack of training and few UK suppliers of machines and biomaterials sources.

The government options to remove barriers are to ensure good coordination of R&D in partnership with industry and incentives for companies to set up in the UK. Other countries barriers include a lack of manufacturing level understanding on how to deal with living tissue. While concepts from other industries can be borrowed, the living component adds an exponential level of complexity. This therefore requires more study and effort to ensure the technology can ultimately benefit patients.

The USA has announced the intent to establish national centres of excellence in manufacturing - one of them will be in Biomedical manufacturing with 50-50 partnership with academia/industry and total Government Funding of $30M. The Fraunhofer Institutes and Chinese Science Foundation have similar initiatives to grow their manufacturing base in this area.

3.5 Cloud computing

Significance in the global economy

Cloud computing allows business to shift its IT needs from a capital-intensive up-front cost model (CAPEX) to an operational cost model (OPEX). The three biggest drivers are flexible scalability and business agility, followed by cost. The model is especially attractive for small start-up and medium sized companies, which cannot support highly qualified staff to support their IT activities. The Cloud consists of on-demand "virtual machines" coupled with software services, which can deliver a wide range of reliable and secure "services" across multiple devices, thus supporting mobile computing. The main services consist of big data, CRM, ecommerce, social and mobile computing, business intelligence, logistics and ERP. Cloud computing may allow new business models and may disrupt present models. For example, SAP's Cloud has 17 million users, the largest of any application provider. The cloud model supports Software as a Service (SaaS) and it is predicted that 82% of applications will be SaaS.

Cloud computing may also lead to new products where services are provided by the cloud rather than being embedded in the device. Examples are the ChromeBook, which offers limited on-board services but at a cheap price point and Android phones, which store data such as contact lists in the cloud.

Cloud computing may also be provided by governments to more effectively "spy" on their citizens. For example, if email services are all provided by a government Cloud then all emails can be read. Similarly, Cloud based ERP systems allow businesses to be effectively monitored.

Synopsis of manufacturing trends

Cloud based ERP systems such as Plex Online which is rated the number-one ERP system for manufacturers, due to its capability to provide the real-time shop floor, quality, and costing information are allowing manufacturing companies to switch from outdated in-house ERP systems to Cloud based systems.

The history of modern cloud computing started after the dot-com bubble when Amazon played a key role by modernizing their data centres, which, like most computer networks, were using as little as 10% of their capacity. Having found that the new cloud architecture resulted in significant internal efficiency improvements whereby small, fast-moving "two-pizza teams" (teams small enough to be fed with two pizzas) could add new features faster and more easily, Amazon initiated a new product development effort to provide cloud computing to external customers, and launched Amazon Web Service (AWS) on a utility computing basis in 2006. Today many companies offer cloud services, including Amazon EC2, OrangeScape, Microsoft's Azure, AT@T Synaptic Compute, IBMSmartCloud, Google App Engine, Dell Cloud Solutions, Levono Cloud, SalesForce, EMC, NTT SeamlessCloud, VMWare, RackSpace etc.

Current issues in manufacture

The biggest inhibitors to cloud computing are 1) uncertainties about security, 2) uncertainties of regulatory compliance, including lack of standards, 3) fear of lock-in, 4) privacy concerns and 5) lack of skills. While cloud computing is often seen as a single concept, it can be broken down into three different models, namely 1) Software as a Service (SaaS), 2) Platform as a Service (PaaS) and 3) Infrastructure as a Service (IaaS). These can be delivered on a private cloud, a public cloud or a hybrid cloud. The hybrid cloud involves the integration of cloud services external to the enterprise with internal data-centre services. Venture capital investment in Cloud computing in 2011 was around one quarter of the $10.5 billion, which comprised all Internet and Web deals (CB Insights 2011).

Mark O'Neill writing in Computing Technology Review dissects the differing security issues in Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (Iaas) (O'Neill 2012):

Software as a Service (SaaS): The critical issue here is password management. Since SaaS delivers applications from the cloud, the main risk is likely to stem from multiple passwords accessing applications.

Platform as a Service (PaaS): The issue here is data encryption. PaaS can be inherently secure, but the risk is slow system performance. Cloud service should automatically encrypt "confidential user data such as home addresses, social security numbers and medical records."

Infrastructure as a Service (IaaS): The issue here is rogue users. IaaS focuses on managing virtual machines, and the risks are little different than with other cloud types. Here, the main risk is rogue or unwarranted commandeering of services.

Cloud computing for manufacturing 20 years out

The cost of computing will be dramatically reduced and will continue to fall. This will allow organizations to deploy more computer resources across the globe, cost-effectively. The value of big data will continue to rise as a strategic asset. Big data analytics will deliver real time visibility into the state of complex operations. Big data analytics coupled with machine learning and artificial intelligence will provide new models for managing enterprises. Cloud computing will allow large parts of an enterprise's operations to be outsourced. The strategic value of the interconnected network will continue to rise - computing has become more reliant on connectivity. Never has this been more true than with cloud computing. In fact, cloud computing is the most network-centric computing model to date and an organisation's ultimate success or failure will be determined by its network strategy. The interdependency of the network and computing will become more critical with each successive wave. With cloud computing, the network is the best way to manage, secure and orchestrate cloud-based resources.

Gartner (Cearley and Smith 2012) has identified five cloud computing sub-trends that will be accelerating, shifting or reaching a tipping point over the next three years and that users must factor into their planning processes:

- Formal Decision Frameworks Facilitate Cloud Investment Optimization
- Hybrid Cloud Computing Is an Imperative
- Cloud Brokerage Will Facilitate Cloud Consumption
- Cloud-Centric Design Becomes a Necessity
- Cloud Computing Influences Future Data Centre and Operational Models

Cloud computing for UK manufacturing

The Technology Readiness Level of Cloud Computing in the UK and abroad is generally at TRL 6. When considering this technology on a 10 point scale it is seen as very important (10) for the future success and competitiveness of the UK in manufacturing activities over the medium and long-term. It is mainly being used in the business, military, and government sectors. Cloud Computing is very important for developing competitive future products (10) and for achieving on-going competitive advantage for Cost (10), Quality (9) and Delivery (9).

In research and development there is a need for development of innovative software applications but there is a shortage of software development expertise.

The main barrier affecting the future uptake and commercialisation of Cloud Computing is the capital costs of equipment and software. One way to remove this barrier would be for Government investment in public and private Clouds where this is occurring in other countries, such as China.

3.6 Cyber/physical security

Significance in the global economy

Three years ago, the head of the British Security Service wrote to hundreds of corporate chief executive officers in the U.K. to advise them that their companies had in all probability been hacked by the government of China. In February, 2013 Mandiant identified a group called ATP1 who have been responsible for attacking 141 organizations. In 2008 the Pentagon reported some 360 million attempts to break into its networks, up from just 6 million in 2006 (Mandiant 2013). On Aug. 15, 2012, Aramco the world's largest oil company was attacked by a malicious virus that affected around 30,000 workstations. On Sept. 19, 2012 the websites of Bank of America (BAC, Fortune 500), JPMorgan Chase (JPM, Fortune 500), Wells Fargo (WFC, Fortune 500), U.S. Bank (USB, Fortune 500) and PNC Bank all suffered day-long slowdowns and were sporadically unreachable for many customers. Security experts call this one of the biggest cyber-attacks they've ever seen. These "denial of service" attacks (huge amounts of traffic directed at a website to make it crash) were the largest ever recorded by a wide margin, according to two researchers.

The Economist in an article on 1 July 2010 describes cyberspace as "the fifth domain of warfare". The UK's National Security Strategy ranks "hostile attacks upon UK cyber space by other states and large scale cybercrime" as a Tier One Priority Risk. It shares Tier One with "international terrorism affecting the UK or its interests", "major accident or natural hazard" and "an international military crisis between states". Tier One risks are identified based on an assessment of the combination of their likelihood and impact.

The Internet which was conceived to connect remote computers in a robust manner that would be resilient to natural faults has proved to be extremely vulnerable to intelligent attacks. The World Wide Web, which was layered on top of the Internet has provided connectivity in a revolutionary manner that has impacted not only business processes but also the very fabric of society. Browser applications developed to facilitate a standard interface to the Web have proved to provide a large attack surface. The latest standards HTML5 have followed the pattern of providing increased usability but at the cost of opening up a massive attack surface.

Synopsis of manufacturing trends

Today's computing environment consists of the Internet and the World Wide Web (the Web). The Internet involves a multitude of devices, such as routers and computers all of which contain complex circuits and software. The rise of counterfeit chips in these networks has alarmed the security forces of most countries. While software attacks gain much of the publicity, the difficulty of detecting counterfeit and malicious chips is at least as significant a problem. This has implications for the manufacture of such chips and devices. There will be a growing market for "secure devices" as the building blocks for "trusted computing".

The Internet created the architecture and transfer protocols through which communications between remote computers could occur. It was architected to be resilient to faulty equipment and to physical attacks (such as an atomic bomb). However, in 1972 when it was first demonstrated cyber-attacks had not yet been conceived. The Internet grew out of the ARPANET and in 1969 the first connection between two computers was established. The Creeper virus was first detected on ARPANET in the 1970s. Creeper was an experimental self-replicating program written by Bob Thomas at BBN Technologies in 1971. The first web site went on line on 6th August 1991. Berners-Lee used a NeXT computer as the world's first ever web server. In 1984 Fred Cohen from the University of Southern California wrote his paper "Computer Viruses - Theory and Experiments". It was the first paper to explicitly call a self-reproducing program a "virus", a term introduced by Cohen's mentor Leonard Adleman. In 1987, Fred Cohen published a demonstration that there is no algorithm that can perfectly detect all possible viruses. Today's viruses are capable of changing themselves on each infection to avoid detection.

Current issues in manufacture

The stealing of inventions and other intellectual property from manufacturing companies is a serious, ongoing strategic threat to British industry (Mandiant 2013).

Another critical area is securing the manufacturing supply chain. Attackers can alter the layout of computer chips at various stages of the manufacturing chain.

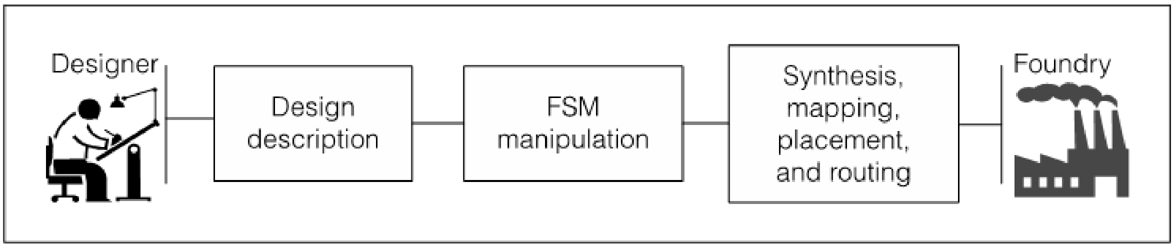


Figure - Chip manufacturing supply chain involving design, finite state machine and placement and routing files

In contrast to hack attacks, where malware or viruses infect the software running on a computer, hardware attack can change the layout of chips in a manner that is difficult to detect. So called "Lab" attacks occur at the design stage and may involve altering the open source design tools used by many companies. Alternatively, the attacker can alter the design files that are sent to the fabricator. Finally, the chips can be physically tampered with during (Fab attacks) or after fabrication to ensure malfunction after a certain period of operation. Simply heating a chip or nicking a connection is sufficient. Counterfeit chips are extremely difficult to detect since their "triggers" to malfunction can be designed to evade discovery during testing.

In 2000 the first Denial of Service attack is attributed to a 15-year-old Canadian with the handle "mafiaboy". It was directed against numerous e-commerce sites, including eBay and Amazon.com, shutting some down at an estimated cost of $1.7 billion.

There are many other forms of cyber-attack including computer worms, Trojan horses, BotNets, rootkits, spyware, key loggers, phishing, spear-phishing and dishonest adware. These attack vectors can be based in computers or within the network itself e.g. in routers and switches. Cyber-attacks can target not only software but on hardware, such as counterfeit chips. Attacks on chips can be pre-silicon, in-silicon and post-silicon. Testing for "doctored" chips is extremely difficult. The US Pentagon has been working to avoid bogus chips from infecting its ballistic missile protection systems. Another problem is the nightmare scenario of “Trojan horse” circuits being embedded in parts. Circuits can easily be added to CAD files and can be extremely difficult to detect during testing, with hiding triggers being a developing art.

Cyber security for manufacturing 20 years out

The US Department of Homeland Security, (DHS 2011) has issued a "blueprint for the future" of cyber security. It centres on Building a Stronger Ecosystem. However, there is considerable debate as to what constitutes a stronger ecosystem. Recent ecology studies show that diversity of species does not necessarily promote survivability. However, it is clear that training a new generation with cyber skills is essential to the future of cyber security. It is also clear that as more devices become connected to the internet or reachable by wireless protocols there will be new attack vectors including: cars, medical equipment and medical implants, cell phones, webcams, smart meters etc.: Social Network Attacks - Malware that steals your e-mail contacts, passwords and other personal information is old news. But a new technical paper by a group of MIT researchers says the cyber security community is ignoring a new, more insidious type of attack: one that preys on your entire social network, working to slowly pilfer information about your behaviour and life (Altshuler et. al. 2011). Dubbed "stealing reality," these types of attacks, the researchers argue, are more insidious because the "victim of a 'behavioural pattern' theft cannot easily change her behaviour and life patterns." Attacks on Cars - In a new paper, Kosher et al. at the University of Washington and the University of California, San Diego, say they have demonstrated "the ability to adversarially control a wide range of automotive functions and completely ignore driver input … including disabling the brakes, selectively braking individual wheels on demand, stopping the engine, and so on" (Kosher et al. 2010).

Medical Devices - Today, wireless pacemakers can send your doctor or hospital real-time data on your heart, showing just how far medical devices have come with the help of modern electronics. But with that new technology comes a new threat: the possibility of someone hacking into your medical device or injecting malicious code that disrupts the lifesaving device. Prosthetic limbs, wireless pacemakers and other implantable medical devices might all be at risk.

Smart Phone Attacks - Most consumers worried about cyber-attacks associate the threat with their home PCs or laptops. So they often think nothing of downloading applications to their smart phones, which often contain just as much personal information as their home computers. More information is available on these problems (James 2009).

Cyber security for UK manufacturing

The Technology Readiness Level of Cyber Security in the UK and abroad is at TRL 4. When considering this technology on a 10 point scale it is seen as very important (10) for the future success and competitiveness of the UK in manufacturing activities over the medium and long-term. It will be important in all sectors and is very important for developing competitive future products (10) and achieving on-going competitive advantage for Cost (10), Quality (10) and Delivery (10).

The present Internet/Web needs to be redesigned to withstand Cyber-attacks but Innovation in Web applications in the UK lags behind the US and there is a critical shortage of cyber expertise and problem awareness. This is a critical area for national and industrial "defence" but there has been a major outflow of IP. The government needs to look at the supply of trained people and methods to retain them in the UK.

The main barriers affecting the future uptake and commercialisation of Cyber Security are the asymmetric nature of attacks, lack of history and understanding, and the large "attack" surface. Generally there is a lack of skilled professionals for this cross-disciplinary problem.

The government options to remove these barriers would be to launch major initiatives in industry, government and universities. The barriers are similar in other countries but the US and Chinese governments are spending many billions to ramp up this area.

3.7 Energy

Significance in the global economy

Fossil fuel energy is synonymous with modern civilisation and all the advances since 1800 when coal fired steam engines first replaced wind power as unreliable, intermittent and costly. Today only 12% of energy comes from other sources (nuclear 5%, hydropower 6% and all other renewables 1%). People in the West consume 6-7 times as much energy per person per day as in 1800, and half of that modern total is used in the manufacture and distribution of material goods, and basic and processed foods (International Energy Agency 2008). The reliability of the energy supplies and of electricity in particular, is taken as a working definition of an advanced society, and its absence is a symptom of underdevelopment.

Synopsis of manufacturing trends over last 40 years

Globally, the energy used per value added has halved in the last 40 years. The International Energy Agency indicates that the total global demand for energy from industry has increased from 1544Mtoe in 1973 to 2422Mtoe in 2010, a rise of 57% much of that drive by a growth in coal, with a small decrease in oil and increase in natural gas (International Energy Agency 2012). While the sectors may not be directly comparable, the growth in industrial output over that period has been from 1T in 1970 ($5T in 2010) to 137T in 2010 (Perry 2011).

Two defining activities have occurred in the last 40 years – the first oil shock in the 1970s, and the recent energy price rises because of shortages due to the rapid increase in demand from China. The first event precipitated a dramatic increase in R&D on renewable energy, but the Mojave desert with its 14K abandoned windmills and several square kilometres of abandoned solar panels is a stark warning about the premature deployment of uncompetitive technologies, another round of which is being rolled out now (Aardvark 2011). In response the oil majors have increased exploration, so that today for every barrel of oil ever consumed, there is another barrel of known reserves, and anywhere between 3-5 barrels yet to be discovered (Eyton 2012). Nuclear energy over this period has grown rapidly, but the combination of accidents at Three Mile Island and Chernobyl stopped further deployment, and since the Japanese tsunami of 2010, an emerging renaissance of nuclear energy has been put on hold. The US price of natural gas has fallen from $13.50 per million BTU to $3.50. In 2000 shale gas provided only 1% of U.S. natural gas production; by 2010 it was over 20% and the U.S. government's Energy Information Administration predicts that by 2035 46% of the United States' natural gas supply will come from shale gas (Stevens 2012).

Current issues in manufacture

Temporary shortages of fossil fuel energy have occurred because of sanctions and infrastructure accidents. They show how quickly civilization can collapse in the absence of energy (c.f. Katrina; where no electricity meant no commerce in a credit card economy and food riots within 24 hours). In the UK, two of three aluminium smelters have closed because of electricity price rises. This represents a double loss to the adjacent communities, as load balancing contracts with the smelters had reduced the cost of electricity to other users. Reliable energy supplies are essential to modern industry. The three-day week in the UK showed the full impact of energy shortages on manufacture. With business as usual, the competition in low cost manufacture has led to ever more efficient manufacturing processes in both energy and materials terms. The dematerialisation of modern society through electronic means is also reducing the number of separate items made – fewer stand-alone cameras, calculators etc., as they all are subsumed into smart phones with a much reduced materials content. This is currently the most effective form of sustainability improvement, which will be taken a stage further once recycling of hand-held electronics becomes pervasive. There is a transition phase while competing and complementary offerings are made, but consumer patterns will settle as manufacturers chase the more profitable options.

Energy for manufacturing 20 years out

There is no reason to expect any major shift in energy availability for global manufacture over the next 20 years. Even those most keen to wean humanity off fossil fuels admit that fossil fuels will still provide most energy through 2030 and even 2050. That does not preclude localised energy supply shortages over the next 40 years as has happened in the past. There are real concerns in the short term in the UK where the numbers simply wont add up through the 2020s unless the commitment to close down all coal-fired power stations by 2016 (under an EU directive) is reversed or there is an accelerated dash for more gas, for which investment decisions are long overdue to prevent shortfalls. A similar situation applies in Germany, exacerbated by the decision to turn off all nuclear power stations, and to replace them by (brown) coal in the short term. There has been a premature dash for alternative energies without a proper approach to whole-life costing, the need to be economically viable, and the total reorganisation of electricity grids to go from broadcasting energy from a few large sites to having to stabilise a grid with multiple small and intermittent sources of energy (for which no stability theorem exists). It is likely that the current dash for renewables will end in failure as it did in California in the 1980s and for the same reasons, not generating enough energy to pay for the maintenance and infrastructure upgrades.

The unintended consequences of this move are not yet fully appreciated. Already industries are choosing to relocate to regions of reliable energy at low cost in order to remain in existence and competitive. It is to be hoped that these energy issues are resolved and solved by 2030. People's memories are not short – the premature roll-out of solar thermal panels in the 1970s in response to the first oil shock that were ugly, oblong, underperforming, and now, rusting has prevented any upturn in deployment over the last decade (Renewable Energy Forum 2010) in spite of unstable energy prices as severe as in the 1970s. What hit is taken by the manufacturing sector in the UK is not clear, but its impact will linger. The opportunity of any major renaissance of manufacturing in the UK is under threat.

The present pace of the rapid growth of Brazil, Russia, India, and China is limited in part by the availability of cheap and reliable energy. As a measure of economic growth, China's CO_2 emissions have grown in each of the last 10 years by more than the total UK emissions, making some of the more draconian EU measures to reduce carbon emissions seem futile.

It is likely on this timescale that solar photovoltaic cells will be absolutely competitive with fossil fuels for whole life cost in certain parts of the world (3000Quads 2012). For widespread deployment a large scale 12 hours storage system is needed, and that there is no obvious scalable technology for this at present. It may make sense to tie solar energy to some forms of manufacture. Wind power will only make sense as an alternative energy if it is in tandem with hydroelectric power capable of providing base load in the absence of wind.

Energy for manufacturing 20 years beyond that

One assumes that the reduction in fossil fuel use will be small, with gains from the penetration of renewable energy being offset by increased manufactures for a larger global population. The increased use of smart appliances controlled by integrated sensor networks will reduce overall energy demand through efficiencies in appliance use. Business as usual will strive to increase the energy efficiency of manufacturing.

The big unknown on this timescale will be whether or not there is a renaissance in nuclear energy: if so, it is unlikely that there will be any structural and global shortage of energy for manufacture. It may be a closer call if there is no nuclear energy. Much of the 2050 target setting in the climate debate is based on the correct assumption that nuclear fusion is unlikely to be a significant contributor to the energy mix in 2050.

Energy for UK manufacturing

When considering this technology on a 10 point scale Energy is seen as very important (10) for the future success and competitiveness of the UK in manufacturing activities over the medium and long-term in all sectors. It is very important for developing competitive future products (10) and for achieving on-going competitive advantage for Cost (10), Quality (10) and Delivery (10).

There has not been enough research and development in historical terms or in view of the upcoming needs and there has been a loss of nuclear engineering with alternative energies being immature and unready. The sector suffers from historically high investments needed to replace an aging infrastructure and a lack of UK-owned energy technology companies.

The main barriers affecting the future uptake and commercialisation of energy technology are politics, finance, manpower and a lack of urgency. The main thing the government could do in this area would be to instil a sense of urgency.

The energy content of manufactured goods is a key ingredient of the cost of manufacture. The closure of UK aluminium smelters is a prime example. Low cost energy is paramount for any internationally competitive industrial sector, and current domestic energy price rises limit what the UK can produce competitively. This will remain so for the next 40 years. If a low carbon economy is privileged in policy terms, then only high value added manufacturing has a role to play. R&D into new energy sources, more efficient transmission systems and more efficient appliances will, if successful, always offer the prospect of lower total energy bills and relative economic prosperity.

3.8 Human-machine interfaces

Significance in the global economy

Interfaces facilitate two-way communication between the human and the machine. Failure to develop interfaces matched to human senses and cognition have led to plane crashes, hospital deaths, financial disasters and nuclear reactor catastrophes (National Research Council 1997). It is of the opinion of the authors that failure to understand the true meaning of the tsunami of data that is now available may lead to further financial disasters in the world's economies.

Synopsis of manufacturing trends over last 40 years

Human-machine interfaces during the Industrial Revolution consisted of gauges, valves, throttles and levers to sense the pressure or temperature and modify flow of energy or to break the progress of the vehicle. With the advent of electricity a host of meters were invented to sense voltage and current and sliders to modify resistance. The automobile developed pedals, a choke and a steering wheel to control the car, which has retained its essence even today. To a large extent the scale of the human controls the scale of the interfaces. Dials are of sufficient scale to be read easily by the eyes. Pedals in a car are of the scale of the human foot. With the advent of the digital revolution with computers and pixel based displays much of the information moved to computer screens. Feedback to machines became text or mouse driven or in the case of airplanes "fly-by-wire".

The most advanced interfaces are possibly today's gaming consoles, such as the X-box and Nintendo's Wii. The Xbox Kinect allows "gesture based control" of the computer. 3D television conveys depth perception to the viewer by employing techniques such as stereoscopic display, multi-view display, 2D-plus-depth, or any other form of 3D display. Most modern 3D television sets use an active shutter 3D system or apolarized 3D system and some are auto-stereoscopic without the need of glasses.

Current issues in manufacture

Inputs from the user are often "mediated" by software. Today's systems include software and hardware that allows human operators to monitor the state of a process under control, modify control settings to change the control objective, and manually override automatic control operations in the event of an emergency. Control centres for infrastructure such as air-traffic control, highway, utility and telecommunication involves dedicated rooms with "walls" of monitors displaying the state of the system. The field of "Big Data Visualization" has become an important topic as the systems we seek to control have become more complex.

Human-machine interfaces for manufacturing 20 years out

One area of research that will develop over the next decade is brain computer interfaces. This is the idea that a computer is controlled purely by thought or, more accurately, brain waves. Several approaches are being pursued, including direct brain implants, full helmets, and headbands that capture and interpret brain waves. An allied area is Biometric and Cybernetic Interfaces. In computing, cybernetics most often refers to robotic systems and control and command of those systems. Biometrics, on the other hand, refers to biological markers that are unique to each person. These are most often used for security purposes, such as fingerprint or retina scanners. 3D displays and 3D graphics will also become prominent. This will require advances in communications technology allowing data transfer rates of terabytes rather than gigabytes per second. The demands for bandwidth will be offset to some extent by compression technologies. Other technologies that will be used include: 1) flexible display technology, 2) augmented reality in heads-up displays (including contact lens displays, 3) voice control, 4) gesture based control including head and eye, 5) futuristic glass, 6) multi-touch table displays.

Human-machine interfaces for manufacturing 20 years beyond that

As systems become more complex the data associated with monitoring and control will be very large - on the order of petabytes. Big Data is a key field and breakthroughs in Big Data analytics, data mining, system simulation, and artificial intelligence will be required.

Human-machine interfaces for UK manufacturing

The Technology Readiness Level of Human-Machine interfaces in the UK is lower (TRL 5) than abroad (TRL 7). When considering this technology on a 10 point scale Human-Machine interfaces are important for the future success and competitiveness of the UK in manufacturing activities over the medium term (8) but very important (10) over the long-term. The main sectors are within business and for military decision making. Human-Machine interfaces are very important for developing competitive future products (9) and important for achieving on-going competitive advantage for Cost (7), Quality (8) and Delivery (8). There is good basis within the UK for developing a competitive edge in Human-Machine interfaces and this area is critical to leveraging a number of other fields such as AI, Big Data analytics etc. and here are few barriers to the UK being successful in this field.

3.9 Joining and coating

Significance in the global economy

Joining and coating technologies are fundamental to manufacture. Strong and long-lasting joints between materials and components are required for products at all scales from buildings and transport vehicles through consumer electronics to the interconnections at the heart of a silicon chip. The joins are always mission-critical, and in many cases they are safety-critical as well. Coatings are also mission- and often safety-critical as well, as they protect the inner materials and the external environment from attacking each other in terms of chemical, corrosion, stress or other factors, and they allow artefacts to be in environments where the uncoated version would fail – not only from wear or tear or corrosion, but also biocompatibility, vacuum tolerance etc.

Synopsis of manufacturing trends over last 40 years

There has been a great broadening of process types for both joining and coating over the last 40 years, and therefore the range of products available. To conventional forms of arc welding, electron beam, laser, electromagnetic pulses and friction stir and contact bonding techniques have been added, to increase the range of materials to be joined, the strength and aspect ratio of the join, the speed of joining, the reduction in any collateral damage etc. We can also add the increasing range, strength, and durability of adhesives. To spray painting and chemical plating have been added chemical and physical vapour deposition, electrochemical techniques, roll-to-roll coatings, powder coatings, sputter deposition, epitaxy and a whole series of technologies often specific to particular classes of materials or scale of coating. Here we omit the processes specific to the electronics industry, as they are highly specialised and dealt with separately. One only has to consider the reliability, efficiency, reliability and the controls of an automobile to encapsulate the improvements in joining and coatings of so many different types of materials over this period. The advance in optical coatings is similarly broad. The status and immediate future of joining was reviewed by the UK Government in a Foresight report published a decade ago (Dolby 2001). There is considerable work in the oil and gas industry concerning coatings – particularly in reducing material corrosion and erosion. This includes the use of additives as modifiers to chemical processes. The use of materials within oils that generate films under high pressure / temperature are prevalent within engines to reduce friction and minimizes wear.

Current issues in manufacture

The current status of welding and joining is best summarised in an international expert review (Smallbone and Kocak 2012). The identified challenges relevant to this study include (1) Environmental sustainability including addressing global warming, CO_2 emissions, waste disposal, decommissioning and recycling. (2) Rapid increase of energy and commodities consumption world-wide related to population growth, with associated demands for manufactured products and resources. (3) Continued R&D in all the technologies listed above, and in materials and their weldability, modelling, light-weight design, structural assessment and extension of the life cycle of structures. (4) Integration of information technology for knowledge management, modelling, technology diffusion, data storage and communication.

The technical literature on coatings is extremely broad, but a major focus is on the developing of coatings for a range of extreme conditions, such as pipelines of all type, dry kilns, and thermonuclear reactor walls. Coatings for pharmaceuticals are being developed for more rapid or more precisely timed release of drugs. The development of possible new technologies e.g. the large-scale transport of supercritical CO_2, superconducting electrical transmission, or breathing but not water transmitting materials for future building insulation, all rely on new and highly specific coatings.

Until about ten years ago coating technology was focused mostly on appearance, durability, costs, mechanical properties and meeting government regulations. Although these factors are still important in developing a new coating, the latest innovative techniques now allow chemists to develop special niche coatings including the self-cleaning, self-healing, biomimetic, super-flexibility and conductive coatings (SpecialChem 2010).

In the area of reel-to-reel processing of films, there are a multitude of technologies that are well understood and developed. The major challenge is to go to very thin, precise films, for example to impart barrier properties on materials such as organic solar cells and in large area displays. This requires the use of techniques such as tensioned web slot coating which require precision of manufacture of equipment as well as in operation.

There has been a general move to coating within clean room environments as functionality and appearance of the layer becomes more critical, particularly for optical and electronic industries.

Nanotechnology is producing a number of new materials that may emerge in coating technologies of the future, including bioactive surfaces (Ma et. al. 2003) or super-hydrophobic coatings (Dobrzańska-Danikiewicz et. al. 2011).

Joining and coating for manufacturing 20 and 40 years out

It would appear that both joining and coating technologies have evolved in capability over the last 40 years without a revolution in either area, and are likely to continue to do so in the next 40 years. They have also evolved in terms of cost reduction and ease of use. Over this next period though, some new trends in manufacturing itself will place new demands on joining and coating and some of these are likely to develop into commercial products. The drivers include environmental concerns. For example the design of products for demanufacture at the end of service life will require joins and coatings that can be unmade with ease and minimum waste.

The move to recycle most products, and in particular electronic products will lead to the development of methods of extracting small amounts of precious materials which may in turn be taken further to recover materials used in adhesives, coatings etc.

Joining and coating for UK manufacturing

When considering this technology on a 10 point scale joining and coating is very important (9) for the future success and competitiveness of the UK in manufacturing activities over the medium and long-term and is used in all sectors. It is very important for developing competitive future products (9) and for achieving on-going competitive advantage for Cost (9), Quality (9) and Delivery (9).

There is a need for research and development with emphasis on compatibility with recycling but the biggest barrier affecting the future uptake and commercialisation is a complacency and conservatism in the face of innovation. It would be useful for the government to initiate awareness exercises.

The breadth of the subjects of both joining and coating, and the impacts that advances play in quite different industries, is such that a cross-sector forum where advances are made known, not just within narrow subfields, but across a broad spectrum, may be a key innovation that Manufacturing 2050 might pursue. It is from such a forum that ideas for broad advances might be constructed and put to the potential end-users to sponsor from R&D organisations.

3.10 Materials technology

Significance in the global economy

Major materials technologies of the 20th century include synthetic gems, cellophane, bakelite, stainless steels, Czochralski crystal growth, pyrex, synthetic rubber, nylon, teflon, silicon transistors, float glass, liquid crystals, optical fibres, etc. This list indicates that nearly all manufacture today comes with an associated technology for the formation of particular materials combinations into useful products. In turn this list comes at the end of millennia of advances where materials have been the name to the past, stone, bronze and iron. Few materials are taken out of the ground and used unprocessed, and the bulk of the $36T annual manufacture is intimately associated with materials processing (WTO 2012).

Synopsis of manufacturing trends over last 40 years

Over the last 40 years, progress has been towards ever more cost effective manufacture of products of ever extending capabilities, and this is likely to continue without let-up over the next 40 years. In historical terms, it will be the development of the materials processing associated with the manufacture of microelectronics that will feature as the most prominent of the recent past. In that timescale, the ability to deposit, remove or change the electronic properties of selected volumes of semiconductor have gone from control at the micron scale in all three spatial dimensions to control approaching 10 atomic spacings in all three spatial dimensions, a volume selectivity that has improved by a factor of 30M. In many others areas of life, the cutting edge technologies have appeared in competitive sports (yachting, motor racing, skiing etc.) and in military applications (night vision, cruise missiles, drone aircraft, communications and bullet proof materials…) where the initial high cost of development is not an insuperable barrier. Subsequent R&D has led to the cost reductions to enable widespread take-up in the professional and consumer markets. The golden age of metallurgy was probably from 1930-1980, whereas that of the other biblical technology, the understanding of glassy materials has been very significant since the 1960s. The whole area of amorphous semiconductors, as used for driver circuits in displays is an example. The range of new synthetic materials for clothing has already almost totally displaced natural products.

Current issues in manufacture

At present the development of new materials technologies is taking place over a broad front, although, as at any time past, there tend to be hot-spot areas where focused research is making more rapid progress. It can be argued that, in concert with the greater advances in biomedicine, new materials technologies in this area promise major advances in the coming decades. With inorganic materials, advances in engineering at the nanoscale will also herald much progress. In general the processing of soft materials (gels, rubbers, fluidics, …) have been making greater progress than say, metal alloys, where the longer timescale of this latter area means that advances have tended over time to saturate (e.g. steel manufacture is recognisably the same process as in the 19th century, even if greater atomistic knowledge allows us to refine the properties further.

Much of the food eaten in developed countries has been processed as a material between the farm where it has been grown and its purchase in supermarkets – to the older pasteurisation of milk, we can add the whole panoply of spreads, pastes, flours, confectionary, etc. In a traditional US supermarket in 2010 there was anywhere between 15K and 60K stock-keeping units, with an average of 38K (FMI 2011). The US Food Marketing Institute tracks the number of items available going back to 1978. It reports that the number of items carried by the average U.S. supermarket rose from 10,425 in 1978 to 40,333 in 2000, an annual growth rate of 6.7 per cent (Klenow 2003). This growth is due to new materials processing of both natural and manufactured products.

In attempting to find new candidate molecules for future drugs, the combinatorics of molecular structure means that very fast processing of materials is needed. In genomics one is seeking to identify billions of base pairs a day. Microfluidic processing techniques are getting there, and will need to go even faster.

Materials technology for manufacturing 20 years out

The current developments in Additive Manufacturing, where selected materials are added to selected volumes in a layer by layer process, with almost no waste, will become widely exploited, if cost-effective products exhibiting the appropriate materials properties can be made. The elimination of waste and the option of mass customisation and local manufacture will herald a major improvement in sustainable manufacture.

The need for more complete recycling will result in a re-optimisation of all materials processing to see if new products can be made that are easier to recycle and reprocess, to have a finite lifetime that is not decades or centuries more than needed, and that comes with adequate warnings of the need for recycling. This should be an important feature of materials technology 20 years from now.

There is no slow-down in the competition in sport or military action, and the trends in terms of new materials technologies will continue. The hazard of pilots being blinded by lasers can be counteracted by glasses/goggles made of materials that can undertake a metal-insulator transition on the rising side of a high-intensity pulse. These materials are available, but hard to process, and could be improved as the speed of laser pulses shortens. The need for sailors to survive for 36 hours in stormy ocean waters in the sub-polar regions represents an unsolved societal need for which materials processing technology will form an integral part of the eventual solution.

It is important to know the limits of what can be done. For transistor operation the dielectric breakdown strength of the semiconductor and the saturated drift velocity of the electrons place firm limits on the speed, voltage and power handling of transistors, no matter how they are made (Johnson 1965). Other sets of limits should be established to cover the wider performance of materials in devices and other applications (e.g. hardness, elasticity, electro-mechanical response). These limits would be able to steer research away from the unattainable.

The man-machine interface is due to become ever more sophisticated over the next 20 years and beyond. The major advances may well be in dealing with the care of an aging population, one of the key demographics of the age, driven by a need to keep escalating costs of people-carers under some control. The materials technologies that represent the interface between (for example) computing signals for controls and living tissue are still primitive, and they are likely to advance in the next 2-4 decades. There will be opportunities in the UK, as the key to successful new products is their design, and the UK is well placed in design to exploit new materials as they emerge.

Materials technology for manufacturing 20 years beyond that

The rapid growth of some technologies came to an abrupt end (e.g. the shaft horsepower of marine turbine engines 1895-1943, the people momentum in jet passenger aircraft 1940-1949) because of a combination of the technical difficulties and the costs of further improvements. This will happen to silicon technology in the next 20 years as Moore's law runs out of steam and the rapid growth of the past 40 years slows down. Chips will evolve over the following 20 years into commodity products, with the efficient use of software being the new discriminator among competing products.

Otherwise the incremental improvement of existing materials, the discovering and processing of materials combinations to ever widen the useful properties of a product will continue through this century as it did in the last. The drivers for more sustainable consumption of materials will come to be on a par with the economics of production in driving this future.

Materials technology for UK manufacturing

The Technology Readiness Level of Materials technology in the UK and abroad depends greatly on the particular material so covers the whole span from TRL 1 for Graphenes to TRL 9 for steels.

When considering this technology on a 10 point scale Materials technology is very important (9) for the future success and competitiveness of the UK in manufacturing activities over the medium and long-term in all sectors. It is also very important for developing competitive future products (9) and for achieving on-going competitive advantage for Cost (9), Quality (9) and Delivery (9).

There is a large activity in research and development across all sectors but there is still little knowledge in industry as to how to maximise the benefit of materials. A national programme of training is required.

There is a considerable amount of research into new materials nationally (a recent example – a national institute of graphene research at Manchester) but introduction of such revolutionary new materials in industrial products, made in the UK, is a significant challenge. Some of the new national centres (e.g. NCC) can cover some gaps but the coverage is still patchy and the role of TSB should be enhanced. A support for new spin-offs and SMEs active in this area is crucial. The UK has a very strong academic base (e.g. graphene). There could be incentives to attract overseas companies to the UK by partnering with spin-off companies or SMEs (linked to universities) here when they employ a minimum number of people in the UK.

The main barrier to exploiting this technology is a lack of knowledge within industry, resulting in a large knowledge gap between basic-research achievements and possibilities for their implementation. It would be useful for the Government to initiate awareness exercises.

There are an insufficient number of university students in materials and, as a result, graduates trained in Materials.

There could be a demonstrated commitment by the UK Government to invest into, and support developments in, this area, comparable with the Materials Genome Initiative, launched by the US Government in 2011. There could be a national programme of training in Advanced Materials and incentives for UK companies in traditional industries to introduce new materials into their products (the hi-tech industries are already doing this under the market pressure) as well as incentives for overseas companies to establish their branches or joint ventures in the UK. The main barrier in most countries is the gap between a rapid introduction and development of new materials and their classes (graphene, metamaterials, nanocomposites, organic materials for microelectronics etc.) and their use in new products. Some countries with a high proportion of high-tech industries (mostly in Asia) are more experienced in this area and are better prepared to face new challenges, while many countries suffer the same barriers as the UK.

Many Asian countries (e.g. China) have a large portfolio of highly-specialised undergraduate programmes that are being swiftly changed or adjusted according to the latest developments; this is in strong contrast with the UK broad undergraduate programmes. Germany uses the link between, on the one hand, its universities and the Max-Planck Society dealing with the basic-research side of advanced materials, with, on the other hand, Fraunhofer Society working closely with industry to accelerate introduction of research ideas and inventions into industrial processes and products. France has various national full-time-research institutions. Many smaller countries (Norway, Sweden etc.) have (apart from universities) various national centres combining both basic and applied research.

3.11 Production systems, including machine tool developments and manufacturing on demand technology

Significance in the global economy

In 2009 the UK Machinery and Equipment Market accounted for over 9% of employee jobs and about 8% of manufacturing GVA (BIS 2010a) and in the UK in 2011 manufacture of machinery and equipment were undertaken by 1,105 enterprises with a combined turnover of £16,478 million. Over the previous 4 years the number of enterprises reduced by about 14% whereas the turnover had increased by 22% (Office for National Statistics 2012). Machinery and equipment manufacturing (NACE Subsection DK) was the core business activity of 174 thousand enterprises across the EU-27 in 2006. These enterprises provided employment for 3.6 million persons in the Member States, The EU-27s machinery and equipment manufacturing sector generated turnover of EUR 621.3 billion in 2006 (Eurostat 2009).

Synopsis of manufacturing trends over last 40 years

A significant change has taken place to Demand-driven manufacturing (DDM) which is an approach to manufacturing where production is based on actual orders rather than forecasts. A key feature of this type of production is the need to track products through the system to maintain control. It has been seen that “Tracking parts throughout a production floor has been an expensive and error-prone proposition; however, that is all changing with the continued evolution of RFID technologies. Enabling one-off manufacturing at mass scale requires an efficient, scalable, and cost-effective tracking mechanism that can be used to manage the floor and drive automated systems to perform the correct manufacturing activities specific to the part. RFID technologies continue to evolve rapidly, improving scanning ranges, environmental tolerances, and reliability. At the same time, costs continue to fall for systems and tags, making the overall cost to track nominal (Kuhn 2012).

Current issues in manufacture

One of the issues in manufacturing is responding to unforeseen orders where products must be delivered quickly. This is being tackled in the US Navy by a program covering Parts-on-Demand. “The objective of Parts-On-Demand (POD) is to reduce the Navy's spare parts supply, stocking, and procurement problems by fabricating parts when needed, in small quantities, in a short time, and for reasonable cost. The need stems from the difficulty of predicting the future demand for that half of the parts for which demand is low. When timing and size of demand are incorrectly predicted, supply and demand are out of balance. Unnecessary costs are borne for uncalled-for parts, whereas procurement delays of a year or more can occur if parts are out of stock when ordered. Delays arise from difficulty identifying the part accurately, assembling the data needed to reproduce it and finding a suitable and willing source” (Nevins et. al. 1983). Manufacturing on demand has been defined as “the ability to manufacture a customised product at different sites using hi-tech fabrication devices driven by software-encoded design instructions and this development would be based on technologies such as rapid prototyping and 3D printing” (Technology and Innovation Futures 2010).

Another area where this philosophy is being employed is within the printing industry. Here the technique is referred to as Print-on-demand and is “in effect a new form of content distribution that makes the production of very low print runs feasible. It is a production system where the whole-required volume can be printed as it is needed. Printing often involves the material being prepared and filed in advance. Files are then sometimes edited according to special requirements specified in the order. The ultimate in print-on-demand is the production of one copy at a time. This is only possible using new digital printing techniques. Unlike so-called short-run manufacturing, defined here as traditional book printing in small numbers (50 – 100) for very limited stockholding, manufacturing on-demand enables the printing of a book as a specific response to a customer order, e.g. on-demand titles will never go into stock. This obviously dramatically reduces hard copy storage and as a consequence reduces inventory, carrying costs and the expense of recycling or destroying unused copies. Moreover it enables on-demand reprinting, which means titles will no longer fall ‘out of print’ (Boguta 2000).

A similar system now exists for the production of CD’s and DVD’s. “Finetunes now offers cd/dvd replication services for its label partners. The facility has been introduced at the request of various labels, with all production taking place in-house on professional equipment. As well as offering short runs up to 300 units, the new service will also provide disc on demand production, making it possible for labels to fulfil direct-to consumer physical sales via important portals like Amazon USA, Germany, France and UK, as well as other independent shops” (http://solutions.finetunes.net/de/manufacturing-on-demand-de/).

A new production paradigm is being proposed for equipment maintenance based on prognostics and health management (PHM). This is often referred to as predictive maintenance. Whereas most maintenance occurs after a failure occurs with PHM the objective is to predict failures in machinery before it happens so that maintenance can be planned properly and so downtime is reduced. This relies on real time information from processes and machines so that trends can be observed. The benefits of this in the semiconductor industry are “reduced unscheduled downtime, Mean Time Between Failures, scrap, and improved uptime, life of consumables, yield and throughput” (Moyne 2011).

Production systems for manufacturing 20 years out

Many of the changes have already been mentioned in other sections such as Automation, Rapid Changeability, and Additive Manufacturing. However, a key aspect of new production systems will be their control and prediction of their performance. It is likely that we will see process maintenance inspired by the biological immune and nervous systems, research has been undertaken to introduce “the transformation of prognostics and health management (PHM) to engineering immune systems (EIS)” (Lee et. al. 2011).

There will be a need for new production systems, particularly the need for agile production systems that are not just a collection of traditional machine tools, but the need to develop the next generation of machine tools. These will be capable of delivering high levels of precision, i.e. advanced laser technologies, and those that can deliver manufacturing solutions for the new class of materials such as graphene and the printed electronics.

Production systems for UK manufacturing

The Technology Readiness Level of Production systems in the UK and abroad is TRL 7 and is seen as important for the future success and competitiveness of the UK in manufacturing activities over the medium and long-term and used in all sectors. When considering this technology on a 10 point scale it has high (7/8) potential for the greatest impact on the future success and competitiveness of the UK in manufacturing activities over the medium and long term. Production systems will be important for developing competitive future products (7) and for achieving on-going competitive advantage for Cost (8), Quality (8) and Delivery (5). The main barriers affecting the future uptake and commercialisation of these areas of technology are the change of supply chains and consumer adoption.

3.12 Robotics/automation

Significance in the global economy

It was interesting that 2011 saw the highest sales of industrial robots ever recorded with sales increasing by 38% to 166,028 units. The main sectors driving this increase were the automotive and metals industry and the main markets were China (22,577 units), USA (20,555 units) and Germany (19,533 units) with growth rates between 39% and 51%. Within Europe there were 43,800 industrial robots sold which was an increase of 43% on the previous year. Although Germany is the largest market for robots in Europe the UK had one of the largest growth rates with sales of 1,514 units which were 72% higher than the previous year. Although the total value of the robotics market is $8.5 billion this does not include the cost of software, peripherals and systems engineering. The worldwide market value for robot systems in 2011 is therefore estimated to be $25.5 billion (IFR 2012).

There was also strong but much smaller growth in ‘service robots’ with sales up from 15,027 in 2010 to 16,408 in 2011. The value of these was $3.6 billion. The service robots are used in defence applications, agriculture, surgery, logistics, construction and demolition systems, and robots for professional cleaning, inspection and maintenance systems, rescue and security robots, mobile robot platforms and underwater systems.

Synopsis of manufacturing trends over last 40 years

Robotics have become much more popular in the last 20 years as they can significantly reduce labour costs and operate in hazardous environments such as ladling molten metal, welding, heavy lifting and spray painting. Although the number of people working in manufacturing has reduced greatly over the last 20 years this is largely due to the increased use of robotics and automation. The range of robotics and automation varies from simple pick and place mechanisms to multi axis robots with vision systems and real time adaption. Some of the earlier sectors to make extensive use of robots were packaging with pick and places systems and automotive for spot welding of a car chassis. The initial systems required extensive teaching to programme all the required movements. This was a laborious process which has largely been replaced by simulation systems where a CAD model of the environment is used to undertake all necessary process planning and clash detection.

Current issues in manufacture

There are still issues to resolve in the design of robotics and automation to reduce the mass of the equipment whilst increasing payload and manipulation. This will need research to optimise structures and employ lighter and stronger materials with power systems that are also lighter. There are still problems that occur due to the positional accuracy of systems and simpler real time measuring and feedback systems are required.

Robotics/automation for manufacturing 20 years out

Robotics and automation will need to be much more aware of their surroundings and especially the presence of humans when they are deployed more in domestic environments.

Robotics/automation for UK manufacturing

The Technology Readiness Level of Robotics/automation in the UK and abroad varies greatly on the topic with some aspects such as real time sensory feedback being at the lower TRL levels (2-3).

When considering this technology on a 10 point scale Robotics/automation is very important (9) for the future success and competitiveness of the UK in manufacturing activities over the medium and long-term in most manufacturing sectors. It is very important for developing competitive future products (9) and for achieving on-going competitive advantage for Cost (9), Quality (10) and Delivery (10).

There is still low hanging fruit in terms of industrial applications and this does not encourage automation system suppliers to stretch their capability. The next challenges are starting to be addressed via the EPSRC Centre for Innovative Manufacturing in Automation and the Manufacturing Technology Centre. This will feed through to industrial reality over the next decade. There are just a few current examples mentioned by the British Automation & Robot Association (BARA) about manufacturing returning to the UK enabled in the main by automated manufacture. So whilst the manual jobs will never be replaced, upgraded jobs such as robot cell designers, programmers, operators and maintenance will increase. The main focus should be to make UK manufacturing competitive via automation and to market products overseas thus increasing exports and GDP, producing stronger and longer lasting employment.

The lack of UK systems integrators for automation solutions has meant that UK industry has had to rely, in the main, on overseas companies to provide solutions. We have the technological understanding in the Universities and the Catapult. We need a national strategy to harness this and support the growth of the UK industry.

The ageing workforce will become a massive barrier to growth and possibly the retention of some industries in the UK. Automation in manufacturing needs to be a national focus with considerably more funding than the currently (very successful) BARA Automating Manufacturing initiative funded by BIS.

There is a lack of training in automation and also poor understanding of business models and automation investment payback. There is a need for retraining skilled workers displaced by automation in manufacturing.

There is also a lack of integration (despite recent initiatives) for EPSRC and TSB to work together on a common funding pipeline approach to research and development activity. Setting aside TSB funds that can be automatically drawn down for development work after the EPSRC research project has delivered needs to be considered.

3.13 Sensors

Significance in the global economy

A sensor (also called a detector) is a converter that measures a physical quantity and converts it into a signal which can be read by an observer or by an (today mostly electronic) instrument. Sensors may be direct, i.e. measuring the temperature as temperature, or indirect, measuring the resistance of an element that has been calibrated against temperature prior to use. All automated equipment, and this includes all machinery used in manufacturing, works on the basis of sensing some aspect of the local environment and using that information to activate (actuate in technical parlance) a response of a piece of equipment. To that extent sensing is pervasive, and is reaching into ever more sophisticated realms of everyday life. A life support system can operate without a person being present all the time, because the breathing, heart-beat, temperature, blood pressure and other phenomena are being sensed, recorded and used to modify if necessary the life support systems. The moniker ‘smart’ referring to control systems depends on sensing providing inputs to the computer that controls the actuation.

Synopsis of manufacturing trends over last 40 years

The definition of sensor above is one that has emerged over the last 40 years in respect of the electrical signal component. In earlier times, a thermometer and a pressure sensor would both be read by reference to the height of a column of mercury. The complexity of the systems driven by sensors has grown hand-in-hand with the capabilities of computers over that time. Sensing has become ubiquitous in that time, as exemplified by their use in automobiles for sensing tyre pressure, breaking action, in collision awareness radar, air-bag deployment, electric windows, fuel injection, revolution counting, and much more that was simply not observed or used in 1970. The range of effects sensed, and of the materials used to sense and to transduce the measurement into an electrical signal, has also increased. The speed of sensing and actuation in response has increased with the capability of computers.

Array sensing has also been developed and widely exploited, especially in medical applications, such as the screening of molecules for new drugs and the description of the human genome. Here the ability to rapidly sense very many assays looking for very small but significant difference in signal has been the key to success.

Security systems for both military and civilian applications have been in the vanguard of sensor development. Motion, trace chemicals, materials stress have depended on increasing sensitivity of the sensing element. In the true battlefield context, countermeasures to increase the awareness of being sensed have also been developed.

There is a whole field of micro-electro-mechanical systems that have arisen from wider uses of the tools for fabricating microelectronics. The sensors that trip air-bags in automobiles are based on a very rapid sensing of the change in acceleration on impact to deploy the airbag.

A whole industry is devoted to remote sensing, including remote sensing from space, to observe patterns of land-use to predict weather and monitor storms and disasters, to spy on military opponents etc.

Current issues in manufacture

Some of the issues are:

- The very small - Miniaturisation has been driven by the semiconductor industry, but many other technology applications have ridden on the initial investments, such as nano-fluidics, and many other aspects of nanotechnology. In these applications the sensors have to be small as well so as to be able to react to the small changes that occur when nano-systems operate and to actuate any response on the timescale of the system, which because of its small scale is intrinsically fast. For that reason nano-electro-mechanical systems are now being developed for sensing and controlling very small systems.

- The dynamic range - in many applications the quantity under investigation may vary in size over many orders of magnitude, e.g. moving objects can go from stationary to several times the speed of sound, and the sensors have to cope with that.
- Noise - Any measurement has some associated noise from the basic quantity being measured – e.g. shot noise in a resistor, and ever more sensitive detectors are based on techniques of detecting real signals in noisy environments.

In some cases the signal being measured may be varying for primary reasons of interest and secondary reasons of no interest, for example a microwave power meter may be intrinsically sensitive to ambient temperature, and this has to be calibrated out, or alternative sensor ideas that are insensitive to temperature must be sought. This extension of the power of sensing elements is a continuing theme in current developments.

Sensors for manufacturing 20 years out

Just as hand-held electronics and the internet have become pervasive over the last 20 years (both being present but relatively embryonic in 1992), so too integrated sensor networks are likely to become pervasive over the next 20 years. Just four of many possible applications include home medical monitoring especially of the elderly, load balancing of electricity aggregated at the city level, automated underground mining, and the autonomous driving of vehicles in dense city traffic. All the elements of such networks are available, but it is the roll-out and the business models that will drive it that will become apparent during this period. The software to control such complex systems with many interacting elements is under development. Already the systems for, say, supermarket logistics, are complex but widely deployed. The smart electricity grid, enabled by smart meters in the home, at work and at other points of use, is widely planned for roll out in the coming two decades. Once the infrastructure is in place the range of sensing applications will explode.

Over the past decade initial research has been conducted on the possibility of monitoring large areas, such as a battle field, or a forest, with a large array of distributed sensors (motes) that are locally autonomous and sense local conditions and report back via radio-link to some base station. The limiting condition is then the power budget of the transmit unit on the mote. The initial idea of cubic motes of 1mm have not been realised because of power consideration, but the principle of the system has been established, and it is likely to find applications on the 20 years' timescale.

The need for recycling of materials in the manufacturing sector is likely to introduce a number of changes in process, some enabled by new sensor technology. At present light bulbs are replaced when they fail, but it may be that pre-failure replacement may result in a better and cheaper recovering of used material, and so intrinsic in-service condition- monitoring may be introduced to refine the timing of upgrades. This happens already in mission critical parts, but a more intelligent use of embedded sensors might have this strategy used more widely.

Sensors for manufacturing 20 years beyond that

Since sensing is essentially an ancillary but important part of any operating system, the frontiers of sensor technology as deployed in 40 years will really not be determined until 30 years out, and will in turn be dependent on the progress in many aspects of materials science, electronics, etc. in the meantime. Many of the topics described in the previous section will become pervasive within 20 years of initial introduction. Although initial sensor networks will control energy, movement etc. of areas already identified, the growing confidence of their successful operation will enable the reach into many areas not considered today, such as: care of the aged, intensive care, totally automated production of personalised products, etc.

Sensors for UK manufacturing

When considering this technology on a 10 point scale Sensors are very important (9) for the future success and competitiveness of the UK in manufacturing activities over the medium and long-term in all sectors and have very high (9) potential for the greatest impact on the future success and competitiveness of the UK in manufacturing activities over the medium and long term. They are very important for developing competitive future products (9) and for achieving on-going competitive advantage for Cost (9), Quality (9) and Delivery (9).

There is a large research and development effort across all sectors and the key to their exploitation will be how to embed sensors in a product and exploit the data produced. The main barrier affecting the future uptake and commercialisation of sensors will be that their full power may not be appreciated. This may be overcome with an awareness exercise.

3.14 Space

Significance in the global economy

The space industry has grown from nothing since the Sputnik was launched in 1957. The early effort was based on research of the space environment and communications with military applications. Since then it has widened out considerably. There are now about 1000 operational satellites in orbit. This and much other material is available in a detailed report from the OECD, (OECD 2011). The top 35 countries examined in this report spent US$65B in 2010 on earth observation, navigation and positioning systems, and telecommunications systems, as well as on continuing space research and military systems work. The pyramid of economic benefits include $50-60B of satellites and launchers, $45-70B in satellite operations, $120-190B in ground-based hardware, $225-325B in derived services and anywhere >$700B in societal effects on society for the decade 1996-2005. The UK Space Innovation and Growth Strategy 2010 to 2030 suggests that the UK should have 10% of the £400B annual space market in 2030 (ukspacedirectory 2010).

Synopsis of manufacturing trends over last 40 years

Whereas it was originally the preserve of the USA, the USSR and European countries, many (~50) countries now have space programmes with spaceflight capabilities either indigenous or in collaboration with small satellite providers such as Surrey Satellite Technology Limited (now in Astrium) (ukspacedirectory 2010). This latter has led the development of the Disaster Monitoring Constellation which has incorporated satellites, owned by Algeria, Nigeria, China, Turkey, UK and Spain. There are now several forums for international space cooperation. Private players are also now entering the market for launching vehicles into space. During the 1960s, the mission to the moon galvanised the US space agencies, and the world public. The momentum carried on into the 1970s with the Apollo programme, but once real applications in earth observation, communications and geo-positioning emerged, the space as a frontier took second place in budgets. There have continued to be space missions to other planets, but at a lower frequency, but with more data from improved technologies on board.

Current issues in manufacture

The space sector has often been considered one of the main frontrunners of technological development, since the beginning of the space age. The number of space-related patents has almost quadrupled in fifteen years (OECD 2011). The countries' share in space-related patents over the 2000-08 period shows the United States and Europe leading, followed by Korea and Japan (OECD 2011). However, in terms of revealed technological advantage, several countries demonstrate a level of specialisation in space technologies patenting, particularly the Russian Federation, France, Israel and the United States (OECD 2011). Surrey Satellite Technology Ltd (SSTL) exploits new terrestrial technologies in space which is outside mere patent counts.

Over the next five years, many advances are expected in the classical sphere of space applications (telecommunications and navigation applications), where satellites could contribute further to the development of commercial information systems and networks (e.g. more broadband to rural areas, high definition and 3D television via satellite, air traffic management). But in addition, several relatively new space systems could be moving from demonstrations to potentially routine systems. They include automatic identification systems (AIS) via satellite which allow countries to monitor ship traffic along their coasts, and space situational awareness, which serves to track the trajectories of operational satellites and large space debris in orbit (OECD 2011). SSTL is opening a debate about the need for Space Traffic Control.

Space for manufacturing 20 years out

The OECD report describes 3 future scenarios for space: smooth sailing (with multilateral international cooperation), back to the future (more regionalisation and geopolitical blocs) and stormy weather (serious international crises in international relations, resource conflicts …) but all three indicate continued military presence, with both civil space and commercial space depending on the particular scenarios (OECD 2011). From this they draw up a promising list of space applications likely to come into widespread use by 2030. The main contenders are listed, many already existing to some degree today.

- Distance learning and telemedicine (broadcasting to remote areas and across national borders, medical remote surveillance).

- E-commerce (enabling changing work patterns due to mobile workforce/home working and economic consequences, HDTV teleconferencing).
- Entertainment (digital radio, TV, data and multimedia broadcasting to fixed [less likely mobile] assets, high bandwidth to the home/convergence of different media) and indeed a space-wide web.
- Location-based consumer services (driver assistance and navigation aids, insurance based on real-time usage data, vehicle fleet management, asset tracking (especially high-value) and road repair management).
- Traffic management (location and positioning of aircraft and ships, optimisation of airport traffic management, optimisation of traffic management – road pricing – driver behaviour logging).
- Precision farming and natural resources management (precision agriculture for maximal efficiency in equipment and application of fertiliser, deforestation and forestry management).
- Urban planning (plans, maps and numerical terrain models, precise positioning of engineering structures and buildings, automatic control of job site vehicles, management and optimisation of job site vehicle routes).
- Disaster prevention and management (telecom capability in absence of ground infrastructure, remote assessment of damage and pollution for insurance claims). A virgin area is the possible predictors of earthquakes from the ionosphere.
- Meteorology and climate change (meteorological and sea condition forecasting for commercial sea shippers, pollution maps with evolution in time, monitoring of the application of treaties, standards and policies).

The key challenges in all this are fourfold: (a) ensuring access to enough radio spectrum that radio interference can be avoided, (b) accessing orbits more cheaply, (c) the rise of innovative terrestrial alternatives to these services, and (d) the resilience of systems that rely on satellites in the event of a failure in space. The latter is often in the context for global rather than national systems.

Manufacture for space is a high-value, low-volume industry, and one dominated by the capability of highly qualified engineers. The UK has a strong history in the manufacture of subsystems and satellites which is continuing to this day, and provided the flow of new talent continues, should grow with the market.

Space for manufacturing 20 years beyond that

The breadth of possibilities thrown up by the scenarios for the next 20 years makes any assessment of likely breakthroughs in the following 20 years exceedingly uncertain The actual pace of progress over the next 40 years will be limited by budgets, skilled manpower, competing priorities, and the perceived value of the returns. By 2050 the space industry will be approaching its centenary. Unlike much of earth-based industry it is unlikely to become commoditised by that time, although sectors might, such as launch vehicles. Commercial space mining of asteroids and the Moon are a possibility in this timeframe. Debris removal missions are also conceivable, especially if a low cost launch is achieved. Space hotels are likely (this is probably the fate of the ISS in the future) rather than short ballistic lobs into space, (which is what Virgin Galactic proposes). Satellite launches using an air-launch variant of the Virgin Galactic system, called Launcher One, are also conceivable. The development of the Skylon vehicle, if pursued, would also make access to space much easier. In the military domain, (and especially in the "stormy weather" scenario), satellites with stealth capabilities are likely, and launch-on-demand responsive space capabilities are a possibility. Huge monolithic satellites like JWST will be replaced by much smaller sub-aperture missions capable of autonomous rendezvous and docking to build up much larger collecting areas in orbit. Formation-flying sparse apertures, (interferometers in space), will be used to explore very long wavelengths, (including the very low RF region which does not penetrate the Earth's atmosphere) and search for gravity waves.

Space for UK manufacturing

When considering this technology on a 10 point scale Space is very important (9) for the future success and competitiveness of the UK in manufacturing activities over the medium and long-term, especially in communications and earth observation. It is very important for developing competitive future products (9) and for achieving on-going competitive advantage for Cost (9), Quality (9) and Delivery (9).

The UK is well placed for space-based services and small satellites and the indigenous growth has been steady rather than spectacular. However, the issue of space debris is a looming problem and there may be a major opportunity there.

The main barrier affecting the future uptake and commercialisation of space technology has been the cost of entry but this is reducing. The Government could facilitate access to missions by having the UK Space Agency act as a broker.

3.15 Ubiquitous computing (Ubicomp)

Significance in the global economy

The vision of computer devices being deployed at many scales throughout our everyday environment is already partially fulfilled. Today people, in industrialized countries, are in constant contact with their work environment and their social network. Smart phones and hand-held tablets are commonplace with multiple wireless channels available including: Wi-Fi, Wi-Max, Bluetooth, RFID, NFC etc. Similarly cars today contain as many as 200 processors with connectivity and monitoring of status being broadcast to central monitoring services. Other devices deployed include, digital audio players, copiers that order their own toner, refrigerators that order items to replace those that have been used, radio-frequency identification (RFID) tags, GPS, intelligent posters and interactive whiteboards. Today supply chains and inventory management depend on RFID and other identification technology to track and trace goods from manufacture to retail.

Synopsis of trends over last 40 years

Mark Weiser coined the phrase "ubiquitous computing" around 1988, during his tenure as Chief Technologist of the Xerox Palo Alto Research Centre (PARC). Research topics in ubiquitous computing include distributed computing, mobile computing, sensor networks, human-computer interaction, Internet of Things and artificial intelligence. To some extent the rise of the smart phone and natural language tools such as Siri have fulfilled the idea of the "personal digital assistant".

Current issues in manufacture

The goal in making things smart is that they should be able to sense, analyse the situation and be able to take action. The challenge today is in the ability of software to fully analyse complex industrial situations. Machine learning and artificial intelligence are making inroads where the context is constrained or simple. However, there is still much research to be done to make our sensing and control systems robust and failsafe.

Ubiquitous computing for manufacturing 20 years out

Ubiquitous computing is the vision of web connected devices being deployed at all scales throughout our everyday environment so that computers are unobtrusive and almost invisible. A parallel idea is that of "context aware" computing, in which things are aware of their own context. So instead of an intelligent robot needing to open a "dumb" door, the intelligent door opens itself for the not so smart robot. The goal is to create a smart environment, full of invisible devices.

Computing in the future will be a constant companion rather than a localized tool. We will be surrounded by context aware compute devices that understand their own role in the environment and can make the environment "smart". These devices will be "context aware" and able to address the 5 W' of Who, What, Where, When and Why. Examples of future devices include:

- Smart Dust - miniaturized devices can be without visual output displays, e.g., Micro Electro-Mechanical Systems (MEMS), ranging from nanometres through micrometres to millimetres.
- Skin - fabrics based upon light emitting and conductive polymers, organic computer devices, can be formed into more flexible non-planar display surfaces and products such as clothes and curtains, see OLED display. MEMS device can also be painted onto various surfaces so that a variety of physical world structures can act as networked surfaces of MEMS.
- Clay - ensemblies of MEMS can be formed into arbitrary three dimensional shapes as artefacts resembling many different kinds of physical object.

Ubiquitous computing for UK manufacturing

The Technology Readiness Level of Ubiquitous computing in the UK at TRL 5 is slightly lower than abroad at TRL 6. When considering this technology on a 10 point scale it is important (7/8) for the future success and competitiveness of the UK in manufacturing activities over the medium and long-term and will be mainly in business, military, government and social areas.

It will be important for developing competitive future products (8) and for achieving on-going competitive advantage for Cost (8), Quality (8) and Delivery (8).

There is a need for research and development to develop innovative software but there is a shortage of software development expertise. There are no significant barriers affecting the future uptake and commercialisation of these areas of Ubiquitous computing.

3.16 Virtual Product Creation (VPC)

Significance in the global economy

Virtual product creation is already happening on a large scale within certain industries, most notably the aircraft manufacturing industry. The prohibitive cost of creating a full-scale (or even part scale) model of a passenger airliner meant that manufacturers such as Boeing and Airbus switch to a totally digital mock-up as soon as computer aided design (CAD) systems were powerful enough to support this. Many of the tests on aircraft components, systems and whole vehicles that would once have been done physically can now be undertaken in the digital domain using software such as mechanical system analysis, finite element analysis and computational fluid dynamics. Automotive companies are not far behind although they still maintain the use of physical prototypes for several reasons, including the legal requirement for crash testing of actual cars. Virtual product creation (and simulation) is now widely available to even small companies as relatively low-cost CAD systems such as SolidWorks can now incorporate virtual prototyping software. The economic benefits of VPC have been seen largely in reduced development costs and cheaper products but also in more optimised product geometries, e.g. for weight saving or fuel efficiency. Some of the geometries being created today would be extremely difficult to create using manual techniques and certainly impossible to analyse without the use of computerised techniques. Much of the virtual product creation software in use is sold by companies located in the USA although there are some notable European players such as Dassault and Delcam.

Synopsis of manufacturing trends over last 40 years

VPC really started with the advent of 3D CAD in the 1970's. Once surface and solid modelling became viable in the 1980's, integration with finite element analysis and other virtual prototyping software became a logical move forward. At first, this was achieved by transferring data from the CAD system to the virtual prototyping system but soon many of the analysis packages were integrated into the CAD systems. Another critical development, especially for complex products, was the advent of product data management (PDM) databases, which enabled large numbers of CAD components with different design versions to be catalogued and monitored digitally. Product life-cycle management (PLM) was really an extension to this, where all data associated with the product throughout its development and usage can be linked to the CAD data. With the increasing power of computers, there has been a steady rise in the size of databases that can be handled and the speed of response for complex calculations such as stress analysis and aerodynamic performance. Calculations that at one time would have taken many hours to compute on a supercomputer can now be accomplished in minutes on a desktop computer. User interfaces for VPC systems have also progressed steadily, mainly becoming easier-to-use but in some cases, increasingly complicated as the rise in functionality of the VPC systems has led to a growing number of icons appearing on the computer screen. The systems have been largely aimed at engineers and a thorough understanding of the underlying engineering principles is still needed if the software is to be used correctly. The use of VPC in the earlier, conceptual stages of design is growing but not yet as ubiquitous as it is in the later stages. This may be partly due to the differing nature of the users, but also because current CAD systems are good at detailed definition of a chosen geometry, but not so suited to the exploration of alternative shapes, as is required in conceptual design. More recently, a few VPC systems have been aimed at the lay user such as Google Sketchup, Tinkercad and 3D Tin. Their aim has been to support those in the “Maker” community (generally home based individuals making one-off parts) who wish to develop their own designs and make them with 3D Printing and other low-cost manufacturing technologies. The functionality of these systems is far below that of mainstream CAD packages and there is no capability for virtual product analysis. None-the-less, they have opened the world of 3D geometric data creation to a much wider audience than was possible previously.

Current issues in manufacture

Within manufacturing industry, the main VPC issues to be addressed are:

- User-interface – there is a tension between giving users access to the increasing range of functions within the VPC systems and keeping the interface simple and intuitive. Research into solving this problem will need to draw as much from psychology as it will from computer science.
- Conceptual design – VPC systems need to support conceptual design better during both geometry creation and manipulation. New modelling techniques may be required, e.g. haptic modelling, and perhaps new ways of storing the 3D data. Automatic conversion of 2D sketches into 3D models would also be very beneficial.
- Customer access – if part (or all) of the product creation task is to be performed by customers or other lay users then the current suite of VPC systems are not suitable. Highly intuitive systems are needed that allow users to “play” with geometry while the “number-crunching” analysis is undertaken automatically in the background to ensure the feasibility and safety of the product. Although initially aimed at lay users, such an interface may also speed up the product development process for the professional design engineer.
- Whole life analysis – VPC and analysis systems need to be better at analysing the usage and disposal aspects of the product life cycle.

VPC for manufacturing 20 years out

Over the next 20 years VPC systems will become increasingly capable of representing every aspect of a product and analysing its performance throughout its entire life cycle. Interfaces will become more intuitive and may move away from the conventional computer screen/mouse model and closer to virtual reality, e.g. a 3D immersive experience. Presentation of the results of analyses will also become easier to interpret. Systems may become more automated with more of the underlying engineering analysis being done without user intervention, opening the way for non-engineers to get more involved.

VPC for manufacturing 20 years beyond that

Beyond 20 years, the scenario could move towards direct conversion of customer requirements into fully-engineered products. There will be a mixture of verbal, visual and tactile inputs and artificial intelligence may be used to “fill in the gaps” or imply additional information when not explicitly given. Analysis of the product design within the VPC will move closer to “virtual usage” enabling the designer (or customer) to experience using the product before it ever exists in reality. The divisions between customer, designer and engineer will become blurred with one person being able to take on all these roles, while supported by smarter VPC software.

VPC for UK manufacturing

The Technology Readiness Level of VPC in the UK and abroad depends on the topic. If defined as CAD, FEA, CFD, etc. it would be TRL 9, however; for new virtual reality interfaces for VPC and direct customer involvement, it is TRL 3.
When considering this technology on a 10 point scale VPC is very important (9) for the future success and competitiveness of the UK in manufacturing activities over the medium and long-term in all sectors.

VPC is very important for developing competitive future products (10) and for achieving on-going competitive advantage for Cost (8), Quality (9) but less so for Delivery (6).

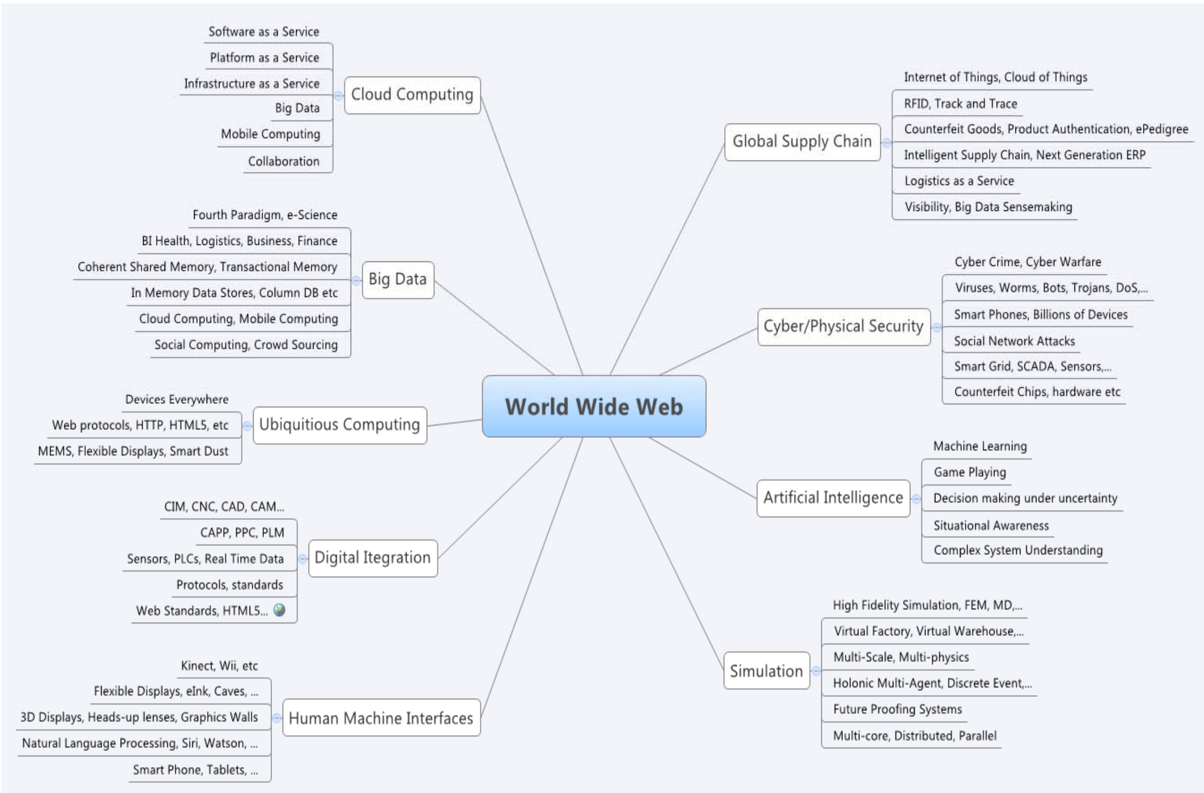
There is a need for research into more intuitive interfaces to enable faster product creation by professionals and easier access to others. Most engineering designers and many industrial designers in the product development arena are aware of virtual product creation techniques that use 3D computer-aided design as their basis. Many of the software tools available have interfaces that are aimed at engineers but they do not support conceptual design so well. New interface development could learn lessons from the gaming industry and other applications of virtual reality. More intuitive interfaces could lead to greater penetration of the creative industries market. One of the main barriers affecting the future uptake and commercialisation of VPC is the current lack of computer-aided design software developers in the UK.

4. Conclusions

It is interesting to see that converging trends (Shipp et. al. 2012) are occurring such as:

- ubiquitous role of information technology
- reliance on modelling and simulation in the manufacturing process
- acceleration of innovation in supply-chain management
- move toward the ability to change manufacturing systems rapidly (what the literature calls rapid changeability) in response to customer needs and external impediments
- acceptance and support of sustainable manufacturing.

Many of these trends are based around IT and the Web/Internet as shown in the figure below (generated by Williams,J.R. MIT).



IT is quickly becoming the basis for most manufacturing. This often starts with analyses of customer needs, representation of products by CAD, analyses and optimisation of designs, production planning and scheduling, CAM, sales and distribution online and performance feedback through complex sensors.

There are still many situations where traditional supply chains exist. For example, a material may be obtained in one country, refined in a second and then converted to a part which would be supplied to a company manufacturing a product. This product would then be supplied to a distributor who would provide smaller quantities to a shop. Through the use of IT the final customer has become able to purchase products directly from the manufacturer thereby cutting out the shop and the distributor. This direct link between customer and manufacturer has enabled IT to be used to generate customised designs.

This is similar to the bespoke manufacturing that was more common a century ago for clothing.

One of the main changes in the supply chain has been the increase of speed for order processing. Previously, the complex supply chain required orders to be consolidated and/or involved lengthy paperwork trails which were slow. The scheduling was then organised and further lengthy processes were involved for the supply of parts.

The manufacture of advanced products will require advanced processes such as Additive Manufacturing but this will also need advanced design methodologies and tools, advanced supply chain management and advanced customers. Design innovation will be the key to exploiting these new materials and processes. The UK has a strong reputation for design innovation. If this could be better directed to these areas then there will be many opportunities for new products and manufacturing facilities located in the UK.

One of the recurring themes with many of the technologies above is a lack of skills base in the UK to fully exploit the opportunities. It has been recognised that “Education and workforce skills are critical elements to the development of advanced manufacturing.” (Shipp et. al. 2012). Connected with most of the technologies listed above the skills shortages range from craft and technician level to Doctorate. As an example it is very difficult to convince new graduates that they should study for another 3 or 4 years to obtain a Doctorate when they are concerned about paying off student loans and missing the opportunity to be established in the job market. This problem is being tackled in Brazil where “most people with a Doctorate (PhD) are employed in the academic establishments. To encourage transfer of people to industry the government pays half the salaries of Ph.D. researchers for their first three years of employment in industry” (Committee on Global Science and Technology Strategies and their Effect on U.S. 2010). Germany has also established new policies with the goal to increase the number of students with PhDs in the workforce and this has stopped the downward trend in university entrants. In the UK the Research Council’s stipend for PhD students should be greatly increased to at least the national average salary for graduates of £25,000 (AGR 2009). The funding for this should be found by diverting some of the HEFCE research money (that is given to universities) to the Research Councils. The allocation from HEFCE to UK universities for the funding of research was £1,699m in 2012-2013 while funding for the research councils in 2012-2013 was £2,573m (BIS 2010b).

There needs to be a rethink of the way technologies move through the TRL levels. The current system expects research funded by the research councils to then move onto TSB activity and often relying on the same academics. A typical TSB project will move a technology by 1 or 2 TRL levels. However, the academics that lead the early research (TRL 1 – 3) generally do not have the same interest in work at later TRL levels. Maybe there is a need for more partnering of academics in different institutions to support different TRL level work.

Many of the technologies listed above do not seem to have a joined up approach as to how they can be best exploited to the benefit of the UK economy. For example in Additive Manufacturing there has been a recent report from the TSB Special Interest Group that discusses how the UK can best exploit this technology. It does identify some education and training needs but the recent work in compiling this current report has shown that there is still much to do in identifying the overall needs and then implementing the policies to ensure the benefits arise. There needs to be a thorough review of each technology resulting in an action plan with clear deliverables, timing and responsibilities for implementation. There also needs to oversight so that the convergent areas are maximised.

In short we will not see the massive subsidies from both the central government and local governments found in other countries such as China (Yan 2012) so we must ensure that we have a carefully thought out plan with agreed timescales and implement it as fast as possible with the current funds available.

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