ROYAL ACADEMY OF ENGINEERING

Emerging technologies and their impact on and use by government departments

A response to Government Office for Science

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Context

The Government Office for Science (GO Science) asked the Royal Academy of Engineering to provide input to work they were coordinating on the Eight Great Technologies – now expanded to include quantum and the internet of things (IoT) – along with their impact on and utilisation by UK government departments.

In summary, Fellows were asked to review a presentation on these (Annex A) with a view to identifying:

a. Additional opportunities for the Eight Great (+ quantum and IoT) to support the work of government departments, or other ways in which they could impact on the delivery of government policy, that are not identified in Annex A.

b. Any anomalies or errors in the impacts that are identified

c. Ways to improve the effectiveness or uptake and application of these technologies by government departments

d. Examples of successful implementation of priority technology areas by governments in other countries.

In particular, GO Science is seeking views on possible opportunities, barriers and actions that cut across two or more departments.

As the UK's national academy for engineering, we bring together the most successful and talented engineers from across the engineering sectors for a shared purpose: to advance and promote excellence in engineering. For the purpose of this response, the Academy consulted a range of expert Fellows from industry and academia.

General comments

> *"The departments and daughter agencies are to be commended for their comprehensive and near-complete set of responses."*

The general consensus was that coordinating efforts around the use of technologies across government is always a good thing and it is important for government to continue working in this manner, identifying cross departmental use of new technologies. Many agreed that it is good to see government taking a lead on choosing technology races rather than trying to recreate government initiatives from other countries. However, some felt that the ten areas identified are merely one way of dividing the total space of technology and science, in the words of one:

> *"I think it is fair to say it is more likely to lead to a technology strategy connected to societal need, industrial strategy and public good than the traditional discipline model but I am not sure it is as valuable for this purpose as a challenge-led model."*

Several issues that weren't covered by the slides in any significant detail include the following:

- Impact of space weather
    - Many of the ten technologies covered involve the development of systems more complex and delicate than those now in common use. To what extent will they be implemented to be resilient against a 'space weather Carrington event', or its terrorist equivalent in an electromagnetic pulse weapon? What opportunities are there for hardening these new technologies?

- Procurement
    - Some stated that government is not yet serious about leveraging procurement to stimulate innovation (such as the Technology Strategy Board's Small Business Research Initiative (SBRI) and that the document misses an opportunity to bring this to the fore. Government needs to move away from the 'buy faster, buy cheaper' mind-set to 'buy smarter, leverage value'.

- Capacity and skills
    - Only two departments identified as a key barrier the question of capacity and skills.

Overall, it was felt that decisions need to be made around what policies might need to be created or adapted. This will not necessarily be relevant for early-stage developments, but should, for example, cover issues such as:

- Environmental and health risks of new materials technologies and synthetic biology
- Cyber-security implications of automation and big data.

Some of the responses, health in particular, show how integration of technologies gives the potential for more benefit than any one technology alone. Mechanisms for achieving and rewarding such integration are few and far between, so one useful addition would be to create a forum around such a set of issues, with academia, commercial and government involvement. The Councils for automotive, and space and their R&D subgroups are examples of good practice in this regard; using this model to cover other areas would be a useful idea to consider.

<u>Technologies with use across government departments and ways to improve the effectiveness of uptake and application of these technologies</u>

Below is a list of technologies that had obvious use across departments and how to improve the uptake and application of these.

Technology specific

- The Internet of Things (IoT)
    - Security of IoT: one Fellow suggested that each generation of computing has failed to learn the security lessons from its predecessor. Most elements of the IoT will be relatively simple systems. It should be possible to design and build these using formal methods thus ensuring security from the beginning. Failure to do so will leave major opportunities for attacks ranging from the irritating to the highly dangerous.

- Quantum technologies
    - It was felt that in quantum technologies many departments limited their ideas to computing and communication, which is missing significant quantum impacts coming from sensing and metrology on a shorter timescale. This point is made on the Technology Strategy Board (TSB) slide, which states "We see opportunities in metrology, sensing and communications before use in computing". Only the TSB, Ministry of Defence (MOD) and National Security Council (NSC) have considered these impacts, which suggests that more work will be required in other government departments to assess the potential impacts of quantum.
    - MOD/Defence Science and Technology Laboratory (DSTL) have made a detailed analysis of the status and opportunities of quantum technologies, which might help this process: http://www.epsrc.ac.uk/newsevents/pubs/dstl-uk-quantum-technology-landscape-2014/
    - One way to improve the uptake and application in this area would be to arrange meetings and educational workshops via the Knowledge Transfer Network (KTN) and the TSB special interest group in quantum technologies.

- Big data
    - The big data topic could include 'data science' topics, e.g. meta-representation, to facilitate synthesis ('mashing') of disparate data types though data fusion to create new inferences.
    - The impact of ever tighter economic integration: over the last 15 years we have used the forerunners of "big data and energy efficient computing" to steadily integrate economies more and more tightly – driving out stock holdings through 'just-in-time' management, slimming down organisations to improve efficiency. Big data may imply a further order of magnitude jump in that integration leading to a whole new set of interdependencies and 'accidental systems'.

  - As well as seeking to reap the benefits of such integration we need to plan how to contain the impact of occasional failures (whether accidental or malevolent) and to limit the extent of cascades of failure. We need to research carefully how to build in the necessary minimum number of 'fire breaks'.
  - Big data and robotics/autonomous systems (RAS) converge for many applications e.g. smart cities, autonomous cars, agriculture, offshore oil and gas, inspection, repair and maintenance.

- Autonomous systems
  - Autonomous systems have strong relevance in advanced manufacturing. Future examples might include hyper-automation of small, modular manufacturing units that could be close to the points of consumption.
  - It may be useful to link procurement by government to the challenges theme in the RAS2020 strategy. This may in part provide an incentive (particularly for SMEs) to compete and win a challenge to achieve preferred bidder status into a possible revenue earning contract and may help to kick-start start-up enterprises.

- Satellites and commercial applications of space
  - The focus on satellites and space should mobilise knowledge of image processing and interpretation with application in other discipline areas e.g. medical imaging.

- Synthetic biology
  - There was nothing about the industrial impact of synthetic biology, which is going to be very significant to the UK economy. For example, in November 2012, the Chancellor gave a speech making this exact point.

- Energy storage
  - It may be useful to require all holders of GR8 Energy Storage funding to provide a 20 minute applications roadmap master class lecture that can be accessible to government departments
  - To improve the uptake and application of energy storage technologies, which can meet the objectives of the 'Eight Great' policy, a process is needed to engage the research community and tech developers with users. That could narrow down a wish-list to a set of applications that could be focused on with targeted support. This could be done under the EPSRC Supergen Hub energy storage roadmap.
  - UK research has been focusing on electrochemical methods e.g. batteries, but we are neither strong nor competitive at manufacturing batteries. On the other hand, the UK has a very strong foundation in thermal and mechanical methods for energy storage and could be world leading in a sustainable manner. For example, the UK invented cryogenic energy storage and is leading in thermal (heat and cold) energy storage materials and processes.
  - The UK could lose leadership and opportunities in these areas if sufficient attention is not put in the research and development. Currently, cryogenic and thermal energy storage technologies are much closer to the applications than other technologies and this requires the government to prioritise and support the area.

Applications can be in large energy storage, hybrid vehicles, localised solar and wind reserves, deployment in tandem with heat recovery from industrial plant, nuclear reactors, among others.
    - The UK is best-placed to develop energy storage technologies for grid-scale application (which could be centralised or aggregated distributed). While the UK does have leading research in new battery technologies, other countries have large-scale manufacturing capability so we are behind the curve and need to look for innovative growth opportunities. There are many applications for small batteries in electronic devices. Warwick Manufacturing Group (WMG) may be focusing on electric vehicle applications.

Effectiveness of uptake and applications

- It is important to encourage systems thinking and cross-departmental consultation. Government should encourage continuing interdepartmental dialogue between analysts (e.g. the EmTech group) and initiate awareness-raising discussions with policy makers (at departmental and cross-government levels). Common challenges, enablers and threats will include:
    - Future cities and infrastructure
    - Cybersecurity at all levels (IoT to Internet) and the need to ensure provenance of data and information
    - Pervasive sensing – it is expected that 30 billion sensors/nodes will connect machines and devices through the IoT by 2020.

- The Academy recommends that all departments use the Chief Scientific Advisors (CSAs) network to interpret technical opportunities for their departments and to plan trials. We also encourage departments to use the Technology Strategy Board's (TSB) Small Business Research Initiative (SBRI) procurement to source consultancy advice on specific areas.

- The bulk of the material covered in the slides is on science and opportunity, not engagement and delivery where government can impact. This is partially addressed by UK Trade and Investment (UKTI) and TSB but rather superficially. More needs to be done here and the Royal Academy of Engineering can make a distinctive input by leveraging its corporate network, connections to academia, communities of practice, the Enterprise Hub and associated industry groups on e.g. energy, built environment.

- There is a lot to do at the interface of disciplines, in applied academia, with engineering academies and institutions and the TSB network, but most importantly, securing the right industrial eco-system with balanced collaboration between the complete range of companies from global multi-nationals through large, mid-sized then SMEs. Government should continue to encourage cross-sector and cross-discipline research programmes – this requires more joining up between research councils and the TSB among others.

- The UK needs more delivery programmes where validated and connected technologies can enhance a number of cross-department systems. For example, the Department for Transport (DfT) and Department for Communities and Local Government (DCLG) addressing links between community planning and citizen mobility, the Department of Health (DoH) and DCLG addressing community health provision.

Department specific:

- Department of Health (DoH)
  - The Internet of Things (IoT) was not highlighted. Among many applications, the IoT's relevance in health includes: wearable wellness monitors, ambulatory diagnostics, patient tracking, capital asset tracking and predictive maintenance.
  - Quantum magnetic sensors could lead to widespread use of magnetic imaging techniques of brain functions, cell communications and sensors with huge impacts on ageing, dementia, cancer and other research areas, as well as novel diagnostic tools in hospitals and GP practices. Quantum imaging techniques could be used to detect cell responses to drugs.
  - Big data: DoH omitted behavioural/lifestyle links to disease Advanced materials – they omitted implantable devices, orthopaedics, artificial organs, new sensors and diagnostics
  - Robotics – robots/autonomous cleaning to reduce infections in wards of theatres along with hospital assistants, rehabilitation systems (prosthetics and physiotherapy) and surgery automation at the micro and nano levels.
  - Life science – there is no reference to genetic repair/genetic engineering or treatment
  - Synthetic biology is likely to have major implications in terms of the development of pharmaceuticals, drug delivery and biosensors for healthcare applications.
  - Regenerative medicine: human remanufacturing is not just limited to cell therapies but increasingly needs to deploy methods of additive manufacturing to enable reconstruction of bones, teeth, skin and ligaments (e.g. University of Birmingham). This would offer large-scale replacement of certain frail body components at low cost in local hospital settings
  - Regenerative medicine: There is an opportunity to focus on the use of technologies already used in advanced manufacturing for those in the biomedical sphere. These methods have so far enabled the development of bio-responsive bone graft replacements, the formulation of materials for cell encapsulation and the production of tissues *ex-vivo.* The next challenge is to scale this up and also move to process for *in-vivo* repair
  - There is no clear attempt to identify and DoH priorities and no reference to any "Foresight", "horizon scanning" or "road mapping" type documents from the department itself,

- Department for Business, Innovation and Skills (BIS)
  - It was felt that there could have been a greater focus on economic/knowledge/capability growth potential of the 10 technologies. There is no reference to the TSB or the various advisory councils that have now been set up, all of which would have had very specific points they would want to make.
  - Quantum technologies: additional opportunities for quantum sensors lie in oil and gas, sustainable cities with underground usage,

healthcare, optical clocks for date stamping for high-value finance (ultra-high frequency trading) and improved GPS.
  - Robotics and autonomous systems: smart cities should be included.
  - Synthetic biology: industrial biology is one application for synthetic biology but there are many others. For example, healthcare, biosensors, fine and bulk chemicals, bioremediation, bioenergy and biomaterials

- Home Office
  - The IoT theme wasn't referenced. Its relevance in the Home Office includes: capital and human asset tracking, pervasive sensing of at-risk environments, tracking legitimate weapons, smaller cameras attached to valuable goods to identify thieves, among others.
  - Quantum technologies – gravity sensors for detection of plutonium or other threats hidden in vehicles
  - Big data: there is a need to consider policy on 'provenance' of data/information and (for example) biosynthesised materials – industry codes of practice required to avoid 'spoofing'
  - Synthetic biology: pollution detectors and pathogen detectors should be included on this slide.
  - Note the sentence on "rapid sequencing" in the agri-science section which should actually be under life sciences.
  - The slide could include augmented reality as an assistive tool for police.

- Department for Environment, Food and Rural Affairs (DEFRA)
  - Internet of things/big data: health monitoring of expensive harvester/agricultural machinery to reduce downtime. There is a link between big data and precision application of pesticides.
  - Quantum technologies: gravity sensors to assess water saturation of dams, ground water levels and movements, gravity sensors on satellites for improved climate models and intelligence on water distribution (e.g. a locally specific version of the GRACE satellite mission detecting ground water levels dropping in India due to irrigation of fields). Magnetic sensors for assessing health of forests, gravitational mapping (e.g. for water), improved sensing and navigation are also relevant.
  - Robotics and autonomous systems: farming becomes more accessible and affordable as RAS capabilities are offered as a service rather than owned and operated by farmers.
  - Energy storage: cryogenic energy systems provide cooling when coupled with solar renewable offer a new and potentially game-changing approach to food security e.g. reducing 30-50% post-harvest losses due to lack of cool. See recent IMechE reports on this important area and interests of US agencies: http://www.imeche.org/news/blog/cold-comforts-farms ; http://www.liquidair.org.uk/files/5414/0429/7516/IMechE_Cold_Chain_Report.pdf
  - DEFRA was the first government department to mention capacity and skills. Note that in the weather section DEFRA didn't mention weather forecasting.

- Department for Work and Pensions (DWP)

- The IoT theme wasn't referenced. Its relevance to the DWP includes: pervasive sensing to improve health and safety at work.
- Quantum technologies: magnetic quantum sensors leading to improvements in dementia research and treatment will have impacts on abilities to live without external help.

- Department for Energy and Climate Change (DECC)
  - The IoT theme wasn't referenced. Its relevance to DECC includes: smart meters, monitoring of domestic PV installations (to optimise availability and maintenance), sensors and actuators for smart heating controls etc. It can also include disposable sensors to monitor local environment e.g. track flow/melting of ice; instrumentation of houses to optimise heating and reduce losses.
  - Quantum technologies could include: quantum computing to lead to vastly improved simulation of climate and molecular design for enhanced photosynthesis (CCS and energy implications); sensing and metrology; gravity sensors for improved oil and gas extraction from existing reservoirs, for supervision of carbon sequestration sites, for assessment of water tables.
  - Satellites play an important role in weather prediction.
  - Energy storage is the missing link in use of renewable energy (for CO2 reduction) and enabling better energy security (this point also applies to BIS). Energy storage is seen as a pathway for economic prosperity and health in developing nations, especially those stranded off-grid since it will enable energy capture from solar sources (this point also applies to DfT and DEFRA) http://www.liquidair.org.uk

- Ministry of Justice (MoJ)
  - It was felt that the MoJ was very thorough in its consideration of the 10 technologies.
  - IoT could also include enhancement to tagging, including location and movement history reporting
  - Quantum technologies: Novel sensors to improve forensic sciences e.g. gravity for searching dead bodies in damp ground
  - Big data – data analytics and visualisation to extract evidence from large datasets; enhanced prisoner/accused person tracking
  - Robotics and autonomous systems: the UK aims to be the world-leader with its legal and regulatory regime. There could be scope for RAS in this area.

- HM Revenue and Customs (HMRC)
  - Again, it was felt that HMRC was very thorough in its consideration of the 10 technologies. However, there could be more focus on policy impacts on HMRC's specific areas of business, such as customs and tax collection.
  - Quantum technologies: detecting of smuggled items using improved sensors, checking weight of freight with gravity sensors
  - Synthetic biology is likely to generate a significant number of jobs in the future, hence it will increase tax yield to cover pensions and other state benefits.

- DfT

- The IoT theme wasn't referenced. For the DfT, IoT impacts include sensor networks monitoring operational performance of infrastructure, benefits of preventative rather than scheduled maintenance and predictive maintenance.
- Quantum technologies include gravity sensors to detect sinkholes, assess health of rail track beds, to gain intelligence on underground composition and suitability for transport infrastructure building projects, magnetic sensors to assess rail tracks and train wheels, clocks and rotation/acceleration sensors for inertial maritime and airborne navigation, substituting or enhancing GPS and precision mapping.
- Robotics: robots can be used for road maintenance and coning of road works to reduce exposure of workers to dangerous traffic.
- Satellites play an important role in weather prediction.
- Advanced materials include better signage/more flexible signage to reduce roadside infrastructure.

- Department for Communities and Local Government (DCLG)
    - The IoT wasn't referenced. For DCLG, IoT has implications in assisted living, reducing the cost of social care to local authorities. It is also relevant to fire and rescue services (e.g. sensors) and building codes (e.g. embedded monitoring and BIM level 3).
    - Quantum technologies: can include gravity sensors for flooding risk assessment, assessment of water penetration in dams along with mapping, navigation and sensing.
    - Big data analytics can synthesise new insights for local authorities
    - Robotics and autonomous systems can provide services in communities such as garbage collection and recycling, education in schools and inspection of water mains.
    - Synthetic biology could include local community support through additional sustainability via synthetic biology, such as recycling waste for energy generation.

- Department for Culture, Media and Sport (DCMS)
    - It was felt that DCMS was very thorough in its consideration of the 10 technologies and should also be commended for picking up on the importance of social media.
    - DCMS may wish to include augmented reality on mobile devices as an enhancement of cultural experiences.

- Foreign and Commonwealth Office (FCO)
    - The FCO placed strong emphasis on overseas linkages to nations with interests in the 10 technologies. It is helpful to include policy adaptations which may result from the adoption of the 10 technologies in international practice. However, it was felt that this was a list of (sometimes trivial) engagements in each area with no evidence of any real strategic choice of engagement or prioritisation.
    - Quantum technologies: the UK already has links to China, India and Brazil in quantum technology, also with respect for satellite missions where quantum sensors were a key topic on the UK-China Space Workshop 28-30 May 2014 in Shanghai.

- Department of Education (DoE)

- Some Fellows felt that there is a need to provide pedagogical resources and training to teachers at primary through secondary levels to support learning about technology in general. The DoE only mentioned how the school curriculum would be changed to address the teaching of these topics and didn't mention social media.
- It appeared that the DoE thought that the IoT would have no direct impact. The IoT could lead to more exciting school projects doing real research and could include remote project work in areas where it is dangerous for children to go to. It could also include tagging and tracking of physical assets.

- Ministry of Defence (MoD)
    - It was felt that the MoD and its agencies were very thorough in their consideration of the 10 technologies. They listed many other key technologies that have come from the DSTL Horizon Scanning Group; however, they didn't mention capability and skills.
    - Internet of things: There is no mention of security, encryption etc. Unless this is considered from the start there is a severe risk of government investment being wasted.
    - Quantum technologies: inertial quantum sensors can be used for submarine navigation, gravity gradiometers for gravity mapping and navigation by gravity maps
    - Defence systems often have to act remotely and without infrastructure backup. Big data will ultimately be limited by the communications system capacity to return the information to the processing engine.
    - Robotics and autonomous systems, UAVs and drones, can lead to reduction in cost of operations. There is also large international market potential, particularly with smaller nations seeking agile, low-cost security systems.
    - Satellites: *"Low-cost launch systems: will enhance the abilities to position communication and sensing satellite systems, increasing situational awareness and surveillance."* One Fellow has asked the MoD to confirm that this is indeed their policy as they had been informed that MoD has no interest in this subject area.
    - Precision GNSS: new surveillance and weapon technologies will necessitate precision position-velocity timing not currently available through GNSS. MoD will need to seek new solutions to provide global centimetric GNSS accuracy.

- National Security Community
    - It was felt that this was a well thought through submission by the Community and its agencies, however, the policy implications may not be publishable.

- Intellectual Property Office (IPO)
    - It was felt that this was a less-strong submission than other departments. It would be useful to see how the 10 technologies might impact policy and practice within the IPO.
    - Synthetic biology was not mentioned in this slide. However, there are likely to be very significant intellectual property issues as the field grows industrially.

- Research Councils
    - Coverage in this form can only be superficial. There is much more depth available elsewhere in terms of Council deliverables. The submission essentially listed the existing funding announcements with no strategy, vision or prioritisation. It would be useful to see how the ten technologies might impact policy and practice within the Councils.
    - The IoT theme wasn't mentioned. This will be an important area for EPSRC/BBSRC/NERC support.

- UK Trade and Investment (UKTI)
    - UKTI's submission provided superficial and partial coverage of the 10 technologies but was indicative of their future plans around these. It would be useful to see how the 10 technologies might impact policy and practice within UKTI.
    - Synthetic biology: industrial biotechnology relates to synthetic biology, but there are many others including healthcare, biosensors, fine and bulk chemicals, bioremediation, bioenergy and biomaterials.

- Technology Strategy Board (TSB)
    - Coverage in this form can only be superficial. There is much more depth available elsewhere in terms of TSB deliverables. It would be useful to see how the 10 technologies might impact policy and practice within the TSB.
    - The IoT theme was missing. This will be an important area for TSB support.

- Financial Services Authority (FSA)
    - The FSA provided a well thought through submission. The only comment the Academy received was that sensing techniques weren't mentioned under quantum technologies.

- Welsh Government
    - The Welsh government provided a well thought through, if superficial, submission. However, some felt it was difficult to see why the Welsh government has many different opportunities and impacts to English government and it lacked a clear strategy or prioritisation for the 10 technologies.
    - Synthetic biology wasn't covered in this slide. There is strong interest and developing collaboration between the Welsh government and the National Centre for Industrial Translation in Synthetic Biology at Imperial College.

Additional opportunities:

- Ten sets of technologies is sufficient and already covers huge scope when funds are very restricted and resource is finite.
- It was encouraging to see that many departments mentioned additive manufacturing as another technology, along with developments in social media.

Examples of successful implementation of priority technology areas by governments in other countries

- Many countries have worked on a challenge-led model where the big problems (whether national or global) have been posed and the technologies harnessed to solve them. Sometimes those challenges have been 'invented', such as the political imperative of US to reach the moon, other times they have been driven by local opportunity, for example ethanol as a fuel in Brazil.

- Other international examples include:

    - Australia's focus on the best means to exploit its very considerable natural resource in Western Australia
    - China's focus on the use of its abundant coal resources
    - Interest from a number of countries in shale gas
    - The DARPA and Small Business Innovation Research (SBIR) programmes in the USA; a series of DARPA-led competitions in the 2000's led to innovation take-up of autonomous car technology by car manufacturers and Google.
    - Mittelstadt manufacturing in Germany
    - Scandinavia's diverse new technology and retail models
    - Singapore's focus on water and healthcare
    - Investment by German, Japanese and Korean governments into the first wave of robotics in the 1990's led to them capturing the international market.

- Some would conclude the evidence is that internationally, this way of cutting the technology space is to engage companies who see a market; however, there is no one size fits all model and internationally the examples are very diverse.

- The 'city government space' is increasingly demonstrating successful implementation of some technologies in individual city systems e.g. Malmo, Sydney, Portland, New York. These are not always national government led due to strong city mayor, political and economic powers.

- Government, with the support of industry and academia, needs to carefully formulate the right model for the UK, taking elements of best practice but using appropriate translation. There is no other model that can simply be applied to the very distinctive UK landscape.

- In relation to the 10 technologies, international examples can be cited for energy storage and quantum technologies:

    - <u>Quantum technologies:</u> the utility of harnessing quantum technologies to revolutionise secure communications is evidenced by the most recent work done by Professor Jianwei Pan of University of Science and Technology of China where significant support has been put forward by the Chinese government.

    - <u>Energy storage technology</u>: Germany, China and USA have put significant resources in thermal energy storage. China has also invested heavily in the liquid air energy storage. Thermal energy storage and liquid air energy storage form an important part of

China's 12th and 13th National Five Year Plans with significant funding from the Chinese Ministry of Science and Technology.

- China State Grid (China government owned) recently built a new research institute called Smart Grid Research Institute (SGRI), which is in parallel to the Electrical Power Research Institute (EPRI). The SGRI is currently building two overseas branches with one in Berlin for Europe and one in the US. The Europe branch is to focus on thermal energy storage and power to gas.

- Germany has put significant investment into energy storage in the thermal, electrical and bioenergy domains. It would be useful for the UK to ensure connections with Germany institutions benefiting from this investment ahead of the forthcoming launch of the Energy Systems Catapult.