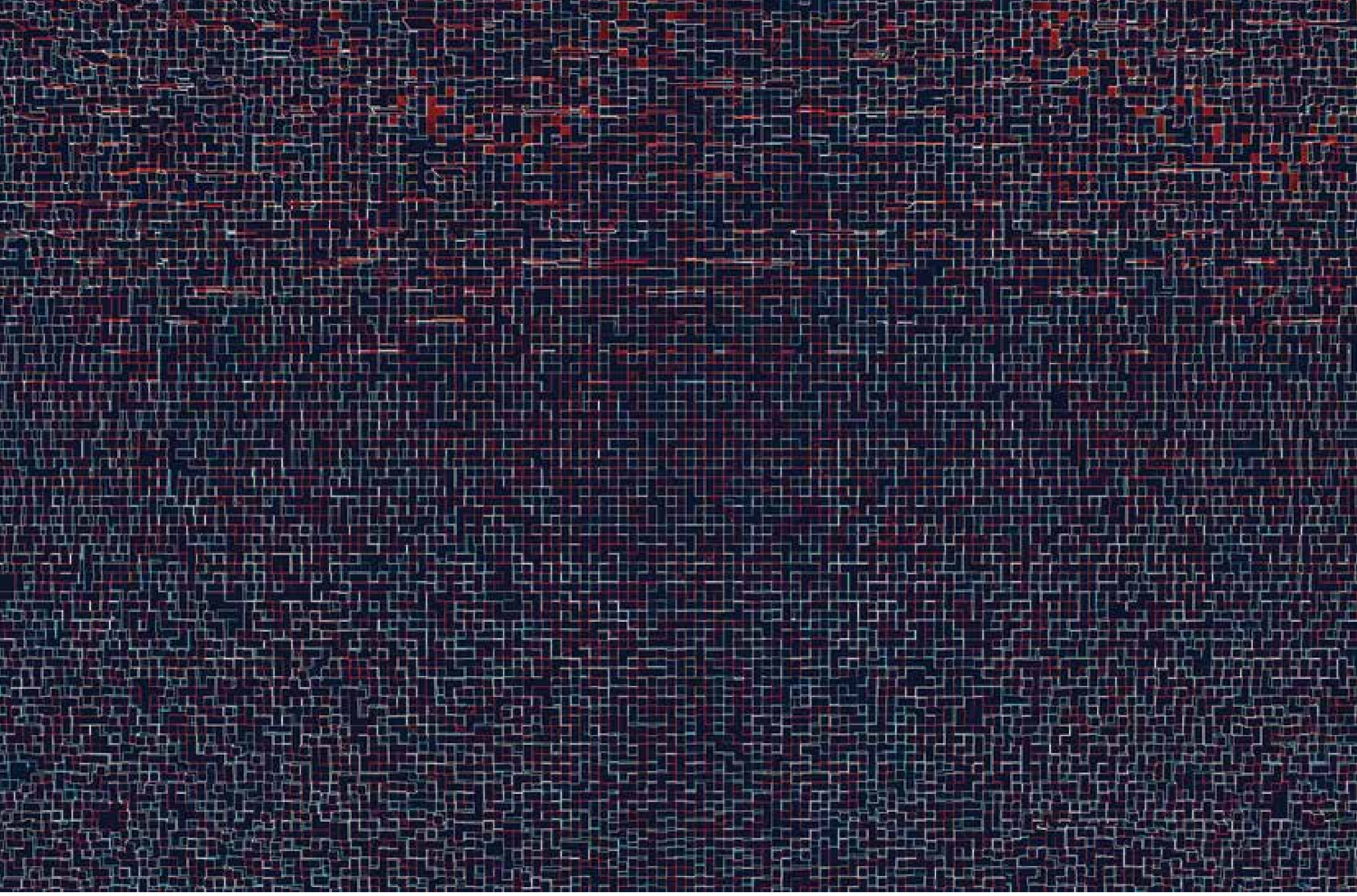

Acceleration of digital innovation by UK manufacturing supply chains

The role of standards

Prepared by BSI

May 2017

bsi.

CATAPULT High Value Manufacturing

IfM MANAGEMENT TECHNOLOGY POLICY

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About

BSI

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Executive summary

There is a great deal of standards activity taking place globally, with those nations who would like to take the lead in their area of specialism leading those activities where they see it as beneficial to their manufacturing sectors. The UK has been slow to coordinate its response to this and our manufacturing sectors run the risk of being left behind. BSI has been working with the Institute for Manufacturing (IfM) and the High Value Manufacturing Catapult (HVMC) to establish where the UK strengths lie that could be exploited via international standards development leadership in digital manufacturing.

As part of this project, the project team studied existing literature on digital manufacturing and engaged with other major stakeholders who had already looked into this area, to build on previous work and to increase the value of the findings in this report.

Building on previous research that highlighted the challenges that BSI and the various manufacturing sectors needed to overcome if our companies are to be internationally competitive, this report proposes a plan for standards adoption and development that would accelerate the rate of innovation by UK manufacturing companies through:

- **International leadership** – Ensuring the UK interests relating to the standards aspects of interoperability are reflected in international standards developments, and that the UK is recognized as a leader in areas of national expertise;
- **Resilient and flexible supply chains** – Rapidly creating the good practice in using and exploiting digital technologies, leading to an increased probability of UK SMEs successfully adopting these capabilities;
- **Security and trust** – Increasing confidence in the use of the technology by using standards to demonstrate security of IP, ownership, and confidence in the information being used to make engineering decisions; and
- **Innovation in the value chain** – Digitizing the value chain opens it up for greater specialization and therefore innovation, which gives rise to potentially new products and services.

Research indicates that the opportunities for the adoption of digital capabilities by UK manufacturing supply chains lie in digitally connecting them end-to-end throughout the life of the product. This connection will not just include machines, but also the behaviours and expectations of the people working in the companies. The fourth industrial revolution will be just as much about digital technologies changing behaviour of people as it will be about developing and adopting new technologies. Additionally the UK has particular strengths in areas such as design and service innovation where we could gain global leadership through first mover advantage by being first onto the international stage through standards.

BSI were invited by HVMC to propose a plan for a standards and regulation working group that would operate as part of a national framework for UK digital manufacturing innovation. All of this will be governed by a steering group of experts reporting into the leaders of the UK digital manufacturing strategy. This steering group will have the role of implementing the strategy, advising on the best routes to implementation and adoption of standards, and identifying where future standards programmes are likely to be required. Through this project, the following priority challenges for standards development were identified.

- **Design for digital manufacturing.** The UK has an opportunity to sustain a leading position in digital design and extend this into through-life support services by supporting development, implementation, testing, and appropriate deployment of product data standards and design good practice. This would be of even more value if the use stage of the product lifecycle was digitally connected to the upstream suppliers who could remain in contact with both the original equipment manufacturer (OEM) and the final product. This requires a major change to the design process, leading to a more collaborative approach. It would also require full connectivity throughout the supply chain, and highly automated quality assurance. The consensus at an industry workshop facilitated as part of this project was that this intervention could drive costs out of the total supply chain and as it applies to the whole supply chain, is something that would benefit from government funding.

- **Simulation, verification and validation (including digital twins and in-process modelling).** The development and use of such capabilities will have a number of benefits, including faster time to market, more flexible and personalized manufacturing lines, and shared data-driven quality assurance. This will require better design for a particular function, compatibility between computer aided design (CAD) and automation packages. Additionally, if companies are to fully benefit from using these capabilities, they will need inputs from a wider number of partners; a more collaborative approach within the supply chain will be required.
- **Intelligent data gathering and analysis.** This priority challenge emerges from the need to discover new value propositions across the through-life value chain by collecting, analysing, and creating knowledge from data. This is important because the creation of a reference architecture for data gathering and analytics to achieve this would enable machine learning and other capabilities to go beyond classical statistical methods and discover new knowledge. This would result in more agile, productive, and sustainable UK manufacturing sectors and would enable the digital sector to innovate in this space.
- **Rights management, data governance and security.** A major challenge emerges from the difficulties in identifying how the ownership of data in a shared environment needs to be recognized, and how revenues would be distributed amongst collaborators. Additionally, issues around data security, reliability, and provenance need to be dealt with. Many relevant standards exist already, and their deployment and adoption may well be key to enabling better rights management, data governance and security.
- **Equipment plug and play, capability and discovery.** A major enabler of higher productivity manufacturing sectors will be the ability to create manufacturing lines that can self-configure, communicate and virtualize their capabilities in the supply chain. In addition, this is something that UK small and medium-sized enterprises (SMEs) need to be able to do to ensure they are not left behind in the competitive global marketplace. What the stakeholders consulted as part of this project considered essential to enable this was:
  - creation of ontologies to define equipment capabilities that automatically call up the relevant standards;
  - integration of equipment and sensors to share data in an open manner; and
  - to do so in a way that does not compromise intellectual property (IP).

The overall programme will be governed by a steering group of experts and follow the approach set out below, with Phases 1 and 2 taking around three months each, and the standards development phase kicking off after six months, and lasting for as long as the platform exists.

Phase 1
Set up

Steering group
Steering group to establish membership, drawing on expertise from existing standards committees, industry representatives from relevant sectors, and other stakeholders as relevant.

Communities of interest
Kick off and deliver initial PAS projects in:
- security-mindedness;
- precision and accuracy of networked-sensor measurements;
- use of data in supply chains;
- collaborative business models; and
- through-life engineering services.

Phase 2
Agree scope with stakeholders

Steering group
Establish and agree existing relevant standards and best practice.

Develop liaisons with existing standards activities and with other relevant bodies.

Develop detailed standards adoption and development strategy, and write business case justifying investment.

Communities of interest
Continue to deliver PAS projects and feed into community of interest strategies.

Phase 3
Standards development

Steering group
Steering group will:
- monitor standards programmes and use outputs where appropriate;
- advise on how to get new and existing standards adopted; and
- advise on new standards as appropriate.

Communities of interest
Deliver standards programme as appropriate, which is likely to be formed of:
- new PAS programme; and
- participation and leadership in formal standards programme, including ISO, IEC and British Standards.

*A PAS is a BSI fast-track consensus-based standardization document.

The overall strategic priorities, and the work of the standards and regulation steering group will be supported by a number of the standards development themes and their respective communities of interest (CoIs). These will be:

- **Theme 1** – Interoperability;
- **Theme 2** – Supply chain capability;
- **Theme 3** – Through-life end-to-end connected supply chains – design;
- **Theme 4** – Governance, security, and assurance of data;
- **Theme 5** – Through-life end-to-end connected supply chains – service innovation.

Each of these themes will operate on an ad hoc project basis and will have a mixture of formal and informal standards activities. The respective CoIs will have appropriate membership representing those stakeholders that are likely to benefit from, or be affected by, the creation of the relevant standards. Such a CoI could be comprised of 150 members or more. These CoIs will be responsible for:

- participation in standards developments where appropriate;
- commenting on draft standards at appropriate stages of development;
- receiving updates on progress of standards and communicating this to the groups that they represent; and
- giving feedback on the relevance and impact of any proposals or work items.

Membership of the CoIs will be drawn from a number of stakeholder groups, including:

- existing standards committees;
- relevant industry sectors, including SMEs as well as large companies;
- metrology institutes;
- regulators; and
- research institutes.

1 Introduction

1.1 Aims and objectives

The main objective of this report is to define the immediate and long-term work programme of standards that will accelerate the capability and competitiveness of the UK's through-life end-to-end digital manufacturing supply chains and value chains.

1.2 Methodology

The project described in this report undertook the following activities, building on a previous project undertaken in 2016.[1]

- Domain research of existing standards and selected industry documents in five identified priority areas, including output from other standards landscaping projects relating to other digital market spaces.
- Design and facilitation of an industry workshop to engage with stakeholders and seek input on draft standardization work programmes, including a stakeholder survey issued to workshop invitees.

The project had the following deliverables.

- Domain research report covering:
  - existing standards and selected industry documents in the five priority areas;
  - output from other standards landscaping projects relating to other digital market spaces (e.g. BIM, smart cities, Hypercat, cyber security) previously conducted by BSI, IfM and HVMC;
  - initial identification of gaps in existing standards landscape of the five priority areas; and
  - stakeholders in the five priority areas, for invitation to validation workshop and potential role in future communities of interest in five priority areas.
- Draft work programmes for each of the five priority areas, including identified potential standards development opportunities and benefits and resource requirements.
- Final project report including:
  - domain research report;
  - prioritized draft work programmes (updated following input from the workshop) for future communities of interest;
  - recommended stakeholder groups for future communities of interest for each of the five priority areas;
  - other workshop outcomes; and
  - draft scope for at least one standard.

This report summarizes the outputs of the project.

1 See Institute for Manufacturing (2016). *Application of digital technologies to innovation in manufacturing, IfM report, 23 September 2016*. Available from: http://www.ifm.eng.cam.ac.uk/uploads/Resources/Reports/Digital_technologies_and_standards_report.pdf

1.3 Standards and digital manufacturing

1.3.1 Standards

Standards are commonly agreed good practice, developed through an open process with relevant stakeholders. They can be used to establish a widely accepted way of doing something of value, including performance demonstration, assurance of a process, agreeing common behaviour, referencing language or exchanging data. They are voluntary tools very different to regulation, where adoption and compliance are legally compulsory. They can also underpin efforts to ensure safety and security, allow interoperability between systems and products, and lower barriers to entry to new participants. Government can often play a key role both in encouraging participation in standards development and raising awareness of the benefits of standards.

1.3.2 Digital manufacturing

Digital manufacturing is a set of activities known internationally by a wide variety of labels, including *Industrie 4.0*, *Smart Manufacturing*, *the Fourth Industrial Revolution*, and *Intelligent Manufacturing*. What each of the concepts described in these ways have in common is the wide range of opportunities arising from the adoption of digital technologies and use of cyber-physical systems within manufacturing supply chains. One German commentator[2] describes *Industrie 4.0* in the following way:

> *'Industrie 4.0 is the German vision for the future of manufacturing, one where smart factories use information and communications technologies to digitise their processes and reap huge benefits in the form of improved quality, lower costs, and increased efficiency.'*

Wikipedia[3] defines *Smart Manufacturing as* follows:

> *'Smart manufacturing is a broad category of manufacturing with the goal of optimizing concept generation, production, and product transaction. While manufacturing can be defined as the multi-phase process of creating a product out of raw materials, smart manufacturing is a subset that employs computer control and high levels of adaptability.'*

In 2016 the German standards bodies DIN and DKE[4] jointly published[5] the second edition of the *German Standardization Roadmap* for *Industrie 4.0*, stating:

> *'With digitization of industrial production, it is essential for extremely divergent systems from various manufacturers to interact reliably and efficiently. The users, operating globally, expect to be able to source their accustomed products and systems everywhere in the world. In order to ensure this global usability and cross-system consistency,* ***international standardization in industrial automation has always been regarded as especially important and pursued as a matter of priority.*** *Nowadays, standards are available or at least being drafted to cover important issues in industrial automation, but new technologies and new requirements repeatedly create a new demand for standardization.'*

2 Zaske, S. (2015). 'Germany's vision for Industrie 4.0: The revolution will be digitised' from *The German View*. Available from: http://www.zdnet.com/article/germanys-vision-for-industrie-4-0-the-revolution-will-be-digitised/

3 See https://en.wikipedia.org/wiki/Smart_manufacturing

4 DIN is Germany's national standards body. DKE is a German national organization responsible for the development and maintenance of electrical engineering, electronics and information technology standards and safety specifications.

5 DIN (2017). *German Standardization Roadmap – Industry 4.0 Version 2*. Available from: http://www.din.de/blob/65354/f5252239daa596d8c4d1f24b40e4486d/roadmap-i4-0-e-data.pdf

Also in 2016, the American National Institute of Standards and Technology (NIST) published *Current Standards Landscape for Smart Manufacturing Systems (SMS)*[6] that said:

> *'In 2014 in the United States, the President's Council of Advisors on Science and Technology (PCAST) issued a report that identified three top-priority transformative manufacturing technologies: Advanced Sensing, Control, and Platforms for Manufacturing; Visualization, Informatics and Digital Manufacturing Technologies; and Advanced Materials Manufacturing. The first two of the technologies enhance the manufacturer's ability to respond to information quickly and efficiently. They, in turn, rely on the effective information flow and system responsiveness that only standards can provide. The PCAST further noted that standards 'spur the adoption of new technologies, products and manufacturing methods. Standards allow a more dynamic and competitive marketplace, without hampering the opportunity to differentiate. Development and adoption of standards reduce the risks for enterprises developing solutions and for those implementing them, accelerating adoption of new manufactured products and manufacturing methods.'"*

Previous work[7] published by the Institute for Manufacturing (IfM) has identified the strategic role for standards in the United States and Germany as being a critical factor in the commercial success of their publicly-funded research and development (R&D) programmes, and this has influenced UK public sector policy towards standards in recent years. The purpose of this project was to build on previous research that identified where investment in standards would help accelerate innovation by supporting the adoption of digital capabilities by UK manufacturing supply chains, and to identify the programmes that would engage with the relevant communities, develop the appropriate standards, and encouraging their take-up.

This project looked at the adoption of digital capabilities throughout the entire manufacturing supply chain, throughout the full lifecycle of the manufactured product. This project built on the outputs of the BSI-IfM digital manufacturing project 2016 (see **1.4**), which developed ten digital scenarios that described how such supply chains would adopt such technologies. None of the existing definitions given above reflect the specific nature and priorities of the UK manufacturing sectors, and the opportunities facing our companies. This project therefore used a new definition that better reflected the interests of UK manufacturers (see **1.4.1**).

1.4 BSI-IfM digital manufacturing project 2016

In 2016, BSI and IfM worked together on a Department for Business, Innovation & Skills (BIS)-funded project[8] to identify the major standards-related challenges that need to be met if UK manufacturing supply chains are to benefit from digital technology adoption.

1.4.1 Definition of digital manufacturing

The 2016 project established the following definition of digital manufacturing:

- digital manufacturing is the **collaborative** transformation of manufacturing through the exploitation of advances in information and communications technology (ICT);

6 Lu, Y., Morris, KC and Frechette, S. (2016). *Current Standards Landscape for Smart Manufacturing Systems*. National Institute of Standards and Technology. Available from: http://nvlpubs.nist.gov/nistpubs/ir/2016/NIST.IR.8107.pdf

7 O'Sullivan, E. and Brévignon-Dodin, L. (2012). *Role of Standardisation in support of Emerging Technologies. A Study for the Department of Business, Innovation & Skills (BIS) and the British Standards Institution (BSI).* Institute for Manufacturing, University of Cambridge. Available from: http://www.ifm.eng.cam.ac.uk/uploads/Resources/Reports/OSullivan_Dodin_Role_of_Standardisation_June_2012__2_.pdf

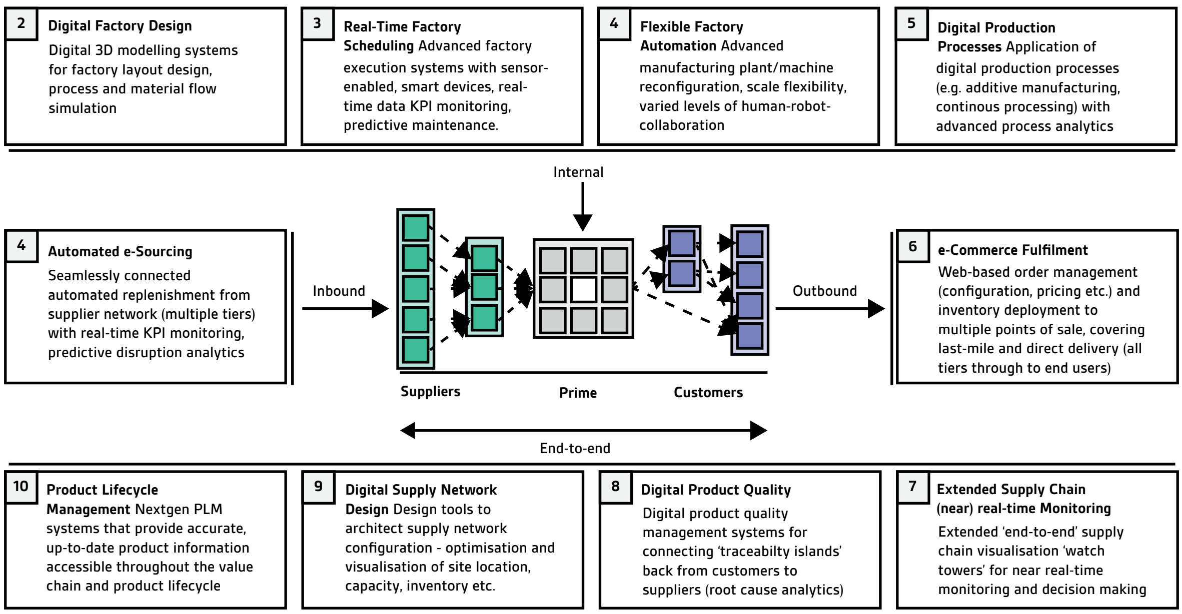
8 Institute for Manufacturing (2016). *Application of digital technologies to innovation in manufacturing, IfM report, 23 September 2016*. Available from: http://www.ifm.eng.cam.ac.uk/uploads/Resources/Reports/Digital_technologies_and_standards_report.pdf

- digital manufacturing transformation enables new supply chain and operations capabilities (scenarios) to emerge that exploit advances in digital technologies, devices, data analytics, data integration and management across the value chain in many sectors;
- digital manufacturing requires the development of new systems engineering competencies (systems modelling, simulation and interface design) and skills (attitudes) across the manufacturing value chain (R&D, design, supply, production, distribution, in service, disposal); and
- digital manufacturing offers significant national and corporate competitive advantage through affordable flexibility, personalization and product/service tailoring.

This definition indicates that the opportunities for the adoption of digital capabilities by UK manufacturing supply chains lie in digitally connecting them end-to-end throughout the life of the product. This connection will not just include machines, but also the behaviours and expectations of the people working in the companies. The fourth industrial revolution will be just as much about digital technologies changing behaviour as it will be about developing and adopting new technologies.

The ten digital scenarios identified in the 2016 project that show how supply chains will adopt digital technologies are shown in Figure 1.

Figure 1 – Ten digital scenarios that show how manufacturing supply chains will adopt digital technologies[9]



1.4.2 Value chain opportunities

A survey of industry stakeholders conducted as part of the 2016 project identified a number of benefits of digital adoption throughout the value chain:

- **R&D:** rapid prototyping and development; digitalization of early discoveries;
- **Design:** quick and low-cost design and redesign; using real manufacturing data at the design stage;
- **Supply management:** visibility, traceability, synchronization and collaboration, effective connection to production stage;

9 Source: Institute for Manufacturing (2016). *Application of digital technologies to innovation in manufacturing*. Available from: http://www.ifm.eng.cam.ac.uk/uploads/Resources/Reports/Digital_technologies_and_standards_report.pdf

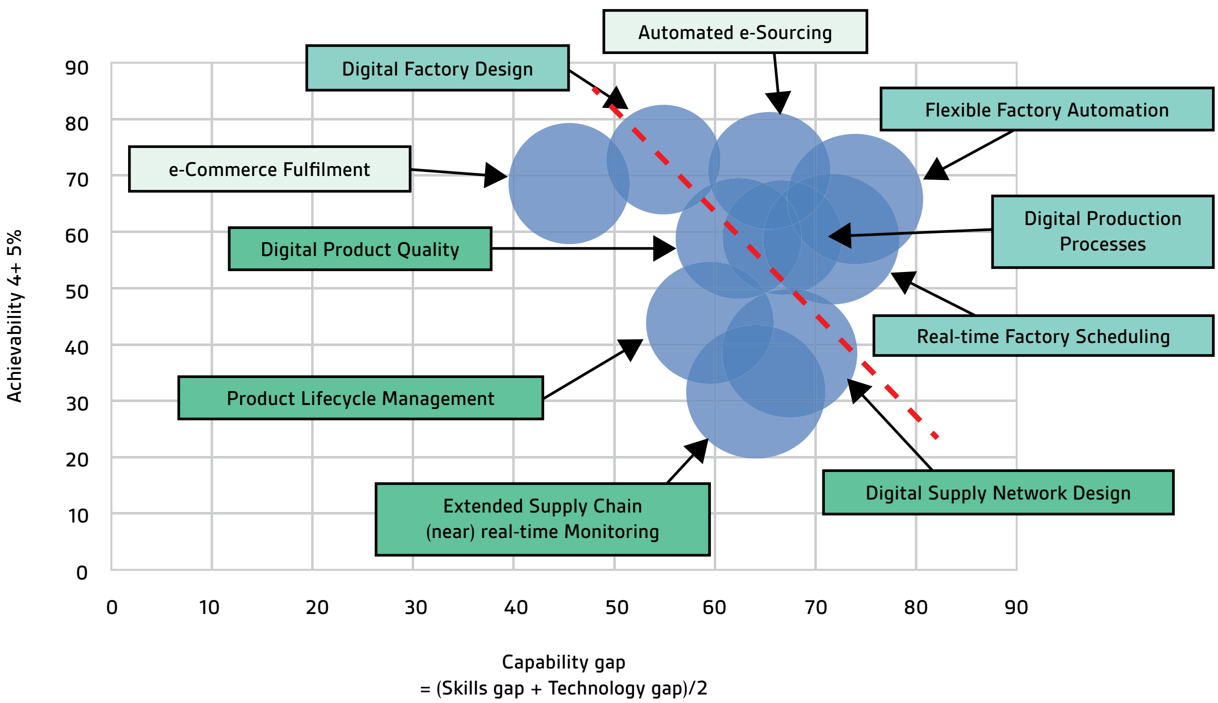
- **Production:** precision, efficiency, integration; making information from vast amounts of data;
- **Distribution:** track and trace, localized demand management, rapid production response to demand changes;
- **Service:** full, real-time service condition monitoring and maintenance, with feedback to design and production;
- **Disposal/re-use:** in-service data to support remanufacture/re-cycle/disposal decisions; and
- **Other:** significant sales and marketing benefits from affordable flexibility, personalization and product/service tailoring.

The UK has a number of strengths within manufacturing, and this gives rise to a number of opportunities building on the inherent entrepreneurial culture within our industries. This is evident in the recurring themes of design and service innovation.

1.4.3 The challenge for UK supply chains

One of the most significant insights to emerge from the 2016 project was estimating the difficulty in achieving the realization of each of the ten digital scenarios identified. Figure 2 suggests that the easiest to achieve would be those that are the responsibility of a single company (such as those that relate to the 'smart factory') whilst the most difficult are likely to be those that need all of the actors in the supply chain to change and align their behaviour. Additionally, the latter scenarios are the ones where the main UK opportunity appears to lie, yet they are more difficult to achieve. This is a significant challenge, and one where the use of standards will have a role to play.

Figure 2 – Mapping the availability of the resources required to realize a particular digital scenario against the capability required to deliver it[10]



10 Source: Institute for Manufacturing (2016). *Application of digital technologies to innovation in manufacturing*. Available from: http://www.ifm.eng.cam.ac.uk/uploads/Resources/Reports/Digital_technologies_and_standards_report.pdf

1.4.4 Standards and digital manufacturing – initial priorities

The 2016 project identified five overall priority areas where immediate action would rapidly enable UK manufacturing supply chains to benefit from end-to-end through-life digital connections. These are as follows.

- **Interoperability of data and machines**. Establish what and how data should be recorded and in which format (e.g. RAMI4.0, ISO Smart Manufacturing SAG, IEC SG8). This is essential in ensuring the efficient and smooth use of data.
- **Using data in a manufacturing context**. Engineering decisions (relating to, e.g. product quality, supply chain optimization and resilience, asset maintenance, design) will be made based on a wide range of fast-moving data. Each actor in the supply chain needs to be aware of how these data are being used, and for what purpose, and therefore what needs to be done.
- **Governance in a digital environment**. How do we make decisions based on others' data? Are the data secure enough and reliable, and is ownership clear? What does the company need to do to manage risks from using data? This may require the establishment of a common decision-making framework across supply chains.
- **Performance assurance of digital twins**. Real, physical systems will be made using virtual modelling capabilities (i.e. digital twins). For these to be widely adopted and exploited there needs to be confidence in their results – assurance.
- **Collaboration**. Digital innovation in manufacturing is driving behaviour away from transactional relationships towards greater collaboration. All actors need to have common expectations and an understanding of the basis of this collaboration and their obligations in the partnership (e.g. ISO 44001, *Collaborative business relationship management systems – Requirements and framework*).

In addition to the above there were further identified challenges where a concerted effort in standards development could add significant value. These were:

- **Human-robot interaction.** There will increasingly be environments where humans and robots work alongside each other, particularly in the production environment. This potentially gives rise to issues relating to ethics and health and safety, and the appropriate use of standards could help to meet these challenges as they arise.
- **Vendor lock-in.** There was a widespread desire that systems should be modular, as truly interoperable company systems, and flexible manufacturing, would require all machines connected in a network to be able to be so without having to be compliant with a particular system or format.
- **Management systems certification.** One recurring theme was on the issue of flexible manufacturing processes, and the potential issue of excessive paperwork requirements for management systems certification being a barrier to adoption. A different approach to quality assurance may be required in this instance.
- **Collaborative lean good practice.** Waste reduction methodologies, such as lean management, add a great deal of value to a particular company, by reducing physical waste, labour required, and time taken to add value within a process. The digital connection of production networks gives the possibility that such techniques could be applied across a number of collaborators in different sites, thereby increasing the potential savings and improvement in performance.
- **Obsolescence management.** The management of long-life products is often challenged by some components becoming obsolescent, and obsolescence management has become an area of expertise, and standardization, in its own right. The role of digital technologies has the potential to create a new paradigm for obsolescence management.

The particular emphasis on through-life digital connection stands in contrast to other activities in this area, such as *Industrie 4.0*,[11] the Japanese *Industrial Value Chain Initiative*,[12] and the European *Road4FAME*[13] collaboration. The focus of each of these is, to date at least, focused largely on digitizing the production part of the value chain and does not have the same emphasis on design and through-life innovation. This demonstrates why the UK needs to establish its own digital manufacturing strategy, and a standards strategy tailored to the particular needs and strengths of the domestic manufacturing supply chains.

11 *Industrie 4.0* is the name given to the German strategic initiative to establish Germany as a lead market and provider of advanced manufacturing solutions. See: https://industrie4.0.gtai.de/

12 The *Industrial Value Chain Initiative* is a Japanese forum to design a new society by combining manufacturing and information technologies. See: https://www.iv-i.org/en/

13 *Road4FAME* focused on architectures and services which facilitate agile and flexible manufacturing processes, ease interoperability in distributed manufacturing environments, support effective collaboration in context-aware enterprises, and provide the foundations for sustainable manufacturing. See: http://road4fame.eu/

2 BSI-IfM digital manufacturing project 2017

In early 2017, a research project was commissioned from BSI by the High Value Manufacturing Catapult (HVMC) as part of a broader proposal to deliver a large scale project (LSP) in digital manufacturing. Standards and regulation would be one strand of the LSP, alongside a number of others.

This project was undertaken by BSI and IfM with the purpose of establishing what specific work programmes would be needed to support wider efforts to accelerate digital manufacturing innovation. This took the form of a standards mapping exercise, a stakeholder survey and an industry workshop. The stakeholder survey and industry workshop used a roadmapping methodology to establish a number of adoption narratives that would describe how UK digital manufacturing would evolve over a number of years, and to inform in more detail what the appropriate standards programmes would need to achieve in order to support this.

As part of the project, the project team studied existing literature on digital manufacturing and engaged with other major stakeholders who had already looked into this area, to build on previous work and to increase the value of the findings in this report. A list of organizations which participated in the industry workshop, by stakeholder type, is given in Annex 4.

2.1 Existing standards relevant to digital manufacturing

As part of this project a domain research exercise was undertaken from a number of sources and across a number of standards databases. The full methodology can be found in Annex 1 and is summarized here.

The following tasks were carried out.

- Extraction of relevant standards that are referenced in the following two freely available reports:
  - Lu, Y., Morris, KC and Frechette, S. (2016). *Current Standards Landscape for Smart Manufacturing Systems*;[14]
  - DIN (2016). *German Standardisation Roadmap Industry 4.0 Version 2*.[15]
- Dissemination of information included in relevant reports to both the digital manufacturing and *Industrie 4.0* emerging areas, the majority provided by the IfM.
- Selection and extraction of relevant key terms and phrases from the reports provided by IfM, as well as from various relevant websites of organizations that play an important part in the digital manufacturing world.
- Development of a 'keyword strategy' with a view to retrieve standards relevant to digital manufacturing.
- Finally, several keyword searches and combinations of both were performed on standards databases using the selected terms and phrases.

Each of the resulting sets of standards search results were then divided into five different stages of the value chain (product design, production, logistics, through-life and end-of-life, and end-to-end connected networks). The numbers of standards within each category is shown in Table 1.

These results suggest that different nations attach a different level of importance to standards at different stages of the value chain. For example, the German roadmap appears to have less of an emphasis on standards for design, logistics and through-life, whereas this comes out more strongly in the BSI model. This suggests that these are priorities for the UK and also potential opportunities for leadership in standardization for UK manufacturing.

14 Available from: http://nvlpubs.nist.gov/nistpubs/ir/2016/NIST.IR.8107.pdf
15 Available from: http://www.din.de/blob/65354/f5252239daa596d8c4d1f24b40e4486d/roadmap-i4-0-e-data.pdf

Table 1 – Standards search results by category

	American (NIST)	British (BSI model)	German (Industrie 4.0)	IfM scenarios	Total
Product design	66	125	—	—	191
Production	146	25	46	427	644
Logistics	—	84	—	102	186
Through-life and end-of-life	—	2	—	11	13
End-to-end connected networks	192	—	219	31	442

Additionally, there is already a great deal of standards development in end-to-end connected machines and in the production environment. This highlights the need for UK manufacturing companies to adopt existing good practice to ensure international competitiveness. The following main conclusions were drawn from the domain research.

- There are opportunities for UK leadership through standards in areas such as design and through-life services. This is partly because they relate to areas where the UK is strong, but also these are areas other nations are putting less effort into in comparison with their own domestic agendas.
- Where many international standards programmes are in place already, it is important to ensure that these are available and adopted by UK companies where appropriate to ensure our supply chains remain internationally competitive.

2.2 Identified UK challenges for standards in digital manufacturing

2.2.1 What does the UK need from a standards programme for digital manufacturing?

The industry workshop with UK stakeholders identified two main objectives for taking action through standards. These are to accelerate the rate of innovation in order to:

- ensure the UK remains internationally competitive and is not left behind by the competition; and
- establish global leadership for the UK in areas of strength.

Any proposed activities need to be aimed at one or both of these objectives. The outcomes of the project have informed the proposed programme for the implementation of the UK digital manufacturing standards strategy set out in this report (see **3**).

2.2.2 Priority challenges

The full roadmapping methodology and analysis used in the stakeholder survey and industry workshop can be found in Annex 2.[16] In summary, the roadmapping efforts, building on the priority areas identified in the 2016 project (see **1.4.4**), identified five priority challenges where a series of standards creation and adoption activities will be critical in achieving success for UK innovation in digital manufacturing. These are as follows.

- **Design for digital manufacturing.** The UK has an opportunity to sustain a leading position in digital design and extend this into through-life support services by supporting development, implementation, testing and appropriate deployment of product data standards and design good practice. This would

16 The full outputs from the industry workshop are given at Annex 3. Workshop attendees are listed by stakeholder type at Annex 4

be of even more value if the use stage of the product lifecycle was digitally connected to the upstream suppliers who could remain in contact with both the original equipment manufacturer (OEM) and the final product. This requires a major change to the design process, leading to a more collaborative approach. It would also require full connectivity throughout the supply chain, and highly automated quality assurance. The consensus at the industry workshop was that this intervention could drive costs out of the total supply chain and as it applies to the whole supply chain, is something that would benefit from government funding.

- **Simulation, verification and validation (including digital twins and in-process modelling).** The development and use of such capabilities will have a number of benefits, including faster time to market, more flexible and personalized manufacturing lines, and shared data-driven quality assurance. This will require better design for a particular function, and compatibility between computer aided design (CAD) and automation packages. Additionally, if companies are to fully benefit from using these capabilities, they will need inputs from a wider number of partners; a more collaborative approach within the supply chain will be required.
- **Intelligent data gathering and analysis.** This work programme emerges from the need to discover new value propositions across the through-life value chain by collecting, analysing and creating knowledge from data. This is important because the creation of a reference architecture for data gathering and analytics to achieve this would enable machine learning and other capabilities to go beyond classical statistical methods and discover new knowledge. This would result in more agile, productive and sustainable UK manufacturing sectors and would enable the digital sector to innovate in this space.
- **Rights management, data governance and security.** A major challenge emerges from the difficulties in identifying how the ownership of data in a shared environment needs to be recognized, and how revenues would be distributed amongst collaborators. Additionally, issues around data security, reliability, and provenance need to be dealt with. Many relevant standards exist already, and their deployment and adoption may well be key to enabling better rights management, data governance and security.
- **Equipment plug and play, capability and discovery.** A major enabler of higher productivity manufacturing sectors will be the ability to create manufacturing lines that can self-configure, communicate, and virtualize their capabilities in the supply chain. In addition, this is something that UK small and medium-sized enterprises (SMEs) need to be able to do to ensure they are not left behind in the competitive global marketplace. What the stakeholders consulted considered essential to enable this was:
  - creation of ontologies to define equipment capabilities that automatically call up the relevant standards;
  - integration of equipment and sensors to share data in an open manner; and
  - to do so in a way that does not compromise intellectual property (IP).

3 Implementation of the UK digital manufacturing standards strategy – accelerating adoption by manufacturing supply chains

3.1 Creation of standards for digital manufacturing steering group

The programme for standards set out in this report would accelerate the adoption of digital technologies and their exploitation by UK manufacturing supply chains by:

- establishing international leadership in areas where the UK has particular strengths, such as design and service innovation;
- ensuring UK manufacturing supply chains are internationally competitive by adopting existing international good practice;
- helping UK companies manage their risks better by protecting their IP and giving them confidence in their data;
- underpinning accelerated innovation in UK manufacturing supply chains by rapidly developing and spreading good practice between sectors, and also from OEMs to their supply chains; and
- contributing to the creation of resilient supply chains in the UK through the adoption of digital technologies.

This standards programme will be governed by a steering group of experts reporting into the leaders of the UK digital manufacturing strategy, which may be the Digital Engineering and Manufacturing Leadership Group. This steering group will have the role of implementing the strategy, advising on the best routes to implementation and adoption of standards, and identifying where future standards programmes are likely to be required.

The overall standards programme will follow the approach set out at **3.3**.

3.2 Standards development communities of interest

Five standards development themes were identified as part of this project:

- **Theme 1** – Interoperability;
- **Theme 2** – Supply chain capability;
- **Theme 3** – Through-life end-to-end connected supply chains – design;
- **Theme 4** – Governance, security, and assurance of data; and
- **Theme 5** – Through-life end-to-end connected supply chains – service innovation.

For each theme, there is a good idea of the focus of work required, and in some cases the scopes of some of the initial standards projects that need to be undertaken. However, in order to develop a more detailed view of all of the standards development projects required, and their respective scopes, there is a need to establish a broader consensus through consultation with stakeholders, including SMEs. For this reason, it is proposed to set up communities of interest (CoIs) for each of the themes identified. The CoIs will report into the steering group and are described below (see **4.2.1** – **4.2.5**).

The CoIs will have appropriate membership representing those stakeholders that are likely to benefit, or be affected, by the development of standards in that theme. The CoIs could be comprised of 150 members or more and will be responsible for:

- participation in standards development where appropriate;
- commenting on draft standards at appropriate stages of development;

- receiving updates on progress of standards and communicating this to the groups that they represent; and
- giving feedback on the relevance and impact of any proposals or work items.

Membership of the CoIs will be drawn from a number of stakeholder groups, including:

- existing standards committees;
- relevant industry sectors, including SMEs as well as large companies;
- metrology institutes;
- regulators; and
- research institutes.

3.2.1 Theme 1 – Interoperability

A key requirement for global standards is that machines and data are platform – and format – independent, and that manufacturers are not locked-in to a particular system or vendor, which would negate many of the potential advantages digitization could bring and reduce competitiveness.

There are currently a number of architecture models[17] that are being made available internationally and it is essential that they reflect the good practice that is already available in an enormous number of international standards published by ISO, IEC and other standards bodies. Additionally, where the existing standards do not sufficiently cover the requirements of the model, the UK should be looking to ensure that new international standards developments reflect UK interests, and may also provide our manufacturing sectors with the potential for international leadership opportunities.

Analysis suggests that international competitors such as Germany and the United States have strongly influenced the international standards agenda in areas relevant to the smart factory. It is essential that UK companies adopt this good practice to remain internationally competitive. However there are parts of the product lifecycle where they have not put in as much effort, such as through-life aspects of interoperability relevant to design feedback and novel services, and this may well be an opportunity for UK leadership in its areas of strength.

It is essential that the UK manufacturing sectors increase their awareness of relevant international standards development, and that even more opportunity is given to them to input into international standards development activities. The CoI is an ideal platform to enable this to happen. Examples of relevant standards activities already taking place are those at IEC Systems Evaluation Group 7, *Smart Manufacturing* and ISO Smart Manufacturing Coordinating Committee (SMCC). In addition to these there are other relevant standards committees where the UK already has significant input, and the incorporation of these into the wider UK digital manufacturing platform would be very valuable to the overall standards programme. Examples include ISO/TC 184, *Automation systems and integration* and its subcommittees:

- ISO/TC 184/SC1, *Physical device control*;
- ISO/TC 184/SC4, *Industrial Data*; and
- ISO/TC 184/SC5, *Interoperability, integration, and architectures for enterprise systems and automation applications.*

17 For example, Reference Architecture Model Industry 4.0 (RAMI4.0), Industrial Internet Reference Architecture, Industrial Value Chain Reference Architecture.

The way to do this is to participate in appropriate BSI standards activities, with BSI acting as the UK member of ISO.

The CoI for theme 1 would have the following terms of reference:

- to be formed by existing relevant standards experts in areas of digital manufacturing, and industrial representatives from the stakeholder industries;
- to assess which of the emerging international standards activities are of critical relevance to UK digital manufacturing, and make this available to UK industry;
- to contribute to existing international standards development activities to ensure the UK voice is heard; and
- to identify where opportunities for UK leadership exist in international standards activities and to ensure these opportunities are realized.

3.2.2 Theme 2 – Supply chain capability

Many UK OEMs are pioneers in the use of digital technologies to add value to their manufacturing capabilities. However, there are real challenges and opportunities in enabling existing manufacturing companies to make the shift to digital, and also enabling digital companies to offer innovative services to the manufacturing supply chain.

Many reports have suggested that a lot of UK SMEs struggle to exploit the data they have, and will therefore struggle even more to build on the opportunities arising from larger amounts of faster data, from a wider variety of sources. They also will need to adopt different business processes and models to fully realize the value of their data, and such companies often struggle to identify the best way of doing this.

The UK also has a vibrant digital SME sector and this could be the basis of a globally-leading capability when applied to the manufacturing sectors.

Both types of SME have a need for guidance on delivering the customer-focused outcomes that digitization of manufacturing supply chains provides.

This CoI would be comprised of relevant supply chain stakeholders from digital and manufacturing companies that collectively have greater expertise in the exploitation of digital technologies. The creation and dissemination of good practice across a range of topics, including digital business models and better use of data, would enable companies to increase their ability to innovate. The standards work programme in this area would be agreed by its members through a consensus programme, but it is envisaged that it would include consideration of existing standards such as ISO 44001, *Collaborative business relationship management systems – Requirements and framework* and ISO 55000, *Asset management – Overview, principles and terminology.*

3.2.3 Theme 3 – Through-life end-to-end connected supply chains – design

Many of the opportunities for UK manufacturing and adoption of digital technologies arise from the connection of the manufactured product in use to the design stage. This builds on existing UK strengths in design and R&D, particularly in high value manufacturing sectors such as aerospace, automotive, and pharmaceuticals, where the UK has a particular degree of comparative advantage. This is reflected in the international leadership of the UK in areas such as ISO/TC 213, *Dimensional and geometrical product specifications and verification*, where BSI recently took over the secretariat, and also in the range of standards published in the BS 8887 series, *Design for manufacture, assembly, disassembly, and end-of-life processing (MADE)* where the UK is pioneering the development of good practice.

A standards programme that accelerates the use of digital technologies for better design would look to build on these strengths and for UK designers to take a global lead in the exploitation of this capability. The research has identified that this is not just better product design, but also leads to the opportunity to establish good practice in designing for a particular purpose (sometimes known as 'Design for X'). This includes:

- designing products for cost-effective service;
- designing products that can be automatically verified;
- designing products that can be digitally manufactured (e.g. using additive manufacturing);
- designing processes that can be incorporated into a flexible system;
- designing supply networks that meet customer requirements better; and
- designing smart factories.

This design expertise will be increasingly relied upon for performance assurance and this will also be a critical area where standards will be needed.

The UK has a strong pedigree in design in high value manufacturing sectors, and exploiting this capability is one area where the UK has a great deal of potential. As previously mentioned, these strengths also mean the UK enjoys leadership in the global standards arena through holding the secretariat of ISO/TC 213 and also through the BS 8887 range of standards.

This CoI would establish how standards could best help businesses exploit the opportunities arising from the use of digital technologies in the design of products, processes, systems, and networks, and how the knowledge already residing within the standards groups could be deployed in achieving this. The terms of reference for the CoI for theme 3 would be:

- to be formed of existing standards experts in design, industrial stakeholders with design expertise and in digital technologies, and other experts able to make a critical contribution;
- to establish which existing standards activities are of relevance to digital manufacturing and to promote their adoption; and
- to identify both national and international standards opportunities where the UK could take a lead, and to ensure these activities take place.

3.2.4 Theme 4 – Governance, security and assurance of data

Alongside interoperability, this theme was consistently amongst the first to arise whenever discussing the role of standards in digital manufacturing innovation. Issues in this theme include:

- security of IP;
- how decisions should be made when using others' data;
- data security, reliability and ownership;
- risk management and mitigation when using data;
- potential legal issues; and
- how to trust data from a wide range of sources, some of which are automated.

If manufacturing supply chains widely adopt digital technologies, then issues relating to governance and security need to be addressed. For example, it may require a common decision-making framework across supply chains to achieve a common way of doing things that all companies can sign up to. Additionally, there are existing standards than can be adopted or adapted for use in this context (e.g. PAS 1192-5, *Specification for security-minded building information modelling, digital built environments and smart* *asset management*). Additionally, whilst digital technologies and automation give a number of potential benefits, safety-critical high value industries have very stringent requirements for assurance relating to performance and safety. Part of the problem is that a lack of confidence in the veracity of the data means their value is limited and any decisions made as a result would be difficult to make. Additionally, we are increasingly using digital models instead of physical testing, so demonstration of performance and safety is likely to be difficult.

Additionally, regulators will also be eager to ensure they can have confidence in the claims of assurance that are made to them and so would likely need to be involved in understanding the role of digital technologies and how this affects regulatory compliance. This theme will look at the role of standards in enabling UK digital manufacturing to be able to use data with confidence, legally, and securely. The terms of reference for the CoI for theme 4 would be:

- to be formed of existing standards experts in information security and governance, industrial representatives with interests in IP and digital, industrial representatives from safety-critical industries using digital technologies, regulators from these industries, experts in certification and assurance;
- to establish which existing standards activities are of relevance to digital manufacturing and to promote their adoption; and
- to identify both national and international standards opportunities where the UK could take a lead, and to ensure these activities take place.

3.2.5 Theme 5 – Through-life end-to-end connected supply chains – service innovation

Digitizing manufacturing technologies opens up the value chain and gives rise to opportunities for novel services that can improve performance. Examples include through-life engineering services that have been developed in the aerospace sector, new ownership models offered by toolmakers, and novel digital services (such as product lifecycle management) that could be offered by digital companies that are not currently operating in the manufacturing sectors.

The CoI for theme 5 would have the following terms of reference:

- to be formed of experts from manufacturing industries looking to create and improve innovative service offerings, and also digital companies looking to enter into the various manufacturing sectors;
- to establish relevant existing standards topics and to promote their adoption;
- to enable the UK to become recognized as a global pioneer in this area by leading international standards developments as appropriate.

3.2.6 Relationship between communities of interest and priority challenges

Each of the priority challenges identified (see **3.1**) will be assigned a lead CoI, as follows.

- Interoperability will lead Equipment plug and play, capability and discovery.
- Supply chain capability will lead Intelligent data gathering and analysis.
- Through-life end-to-end connected supply chains – design will lead Design for digital, and also Simulation verification and validation.
- Governance, security, and assurance of data will lead Rights management, data governance, and security.

3.3 Initial work programme

Through the course of this project, BSI has received sufficient stakeholder input to indicate the following publicly available specification (PAS) projects should be initiated and would enable UK manufacturing to rapidly make progress. These could be delivered immediately. They are as follows.

- **PAS setting out good practice for the use of data in manufacturing supply chains (Theme 2).** A number of studies[18] have shown that UK manufacturing SMEs often find it difficult to fully exploit the data they already have, and the potential value of data in future is only going to increase as it becomes greater in volume and variety, available in a more timely fashion, and of known veracity. It is important that UK manufacturing SMEs quickly improve their capacity and capability for exploiting data. Through the PAS process, good practice will be developed that can quickly be taken up, thereby improving the UK's ability to exploit digital manufacturing technologies.
- **PAS to accelerate the move towards collaborative relationships within manufacturing supply chains, moving away from the previous transactional way of doing things (Theme 2).** A finding from the industry workshops suggests the most striking change that will result from the fourth industrial revolution will be that supply chains will no longer behave in a transactional manner, they will move towards more collaborative relationships. The will require new business models and a change of behaviour to enable these models. This requires large numbers of actors in the supply chains to change and align their behaviour for this to be effective. BSI pioneered this concept through the development of BS 11000, *Collaborative Business Relationships Management System* (which has now been replaced by ISO 44001) and this understanding could be transferred into a PAS for digitally connected manufacturing supply chains.
- **Security mindedness PAS for digital manufacturing (Theme 4).** The use of digital technologies in manufacturing supply chains will not happen if issues around data governance are not resolved. The UK digital sector has a great deal of expertise in this area, and existing good practice can be transferred from this sector into manufacturing to ensure genuine barriers to adoption of digital technologies are overcome. BSI has an existing standardization document in this area: PAS 1192-5, *Specification for security-minded building information modelling, digital built environments and smart asset management*, and another in development: PAS 185, *Smart Cities – Specification for establishing and implementing a security-minded approach*, and this understanding could be applied to the digital manufacturing context.
- **PAS setting out good practice in establishing the precision and accuracy of connected sensor measurements in a widely distributed network (Theme 4).** Sensor networks connected using internet of things (IoT) capabilities have the potential to give rise to significant benefits, generating valuable data in real time. However, the information being generated by these networks is often poorly qualified, leading to the data not being trusted. It is clear that good measurement practice needs to be adopted by users and developers of these technologies, and this PAS will be the first step in that direction.
- **PAS setting out a common vocabulary and good practice in the design and delivery of through-life engineering services (TES) (Theme 5).** The UK has shown strong leadership in the TES area, establishing new ways of creating value and new business models offered by digitally connecting a product throughout its operational life. One barrier to progress has been difficulty in quickly putting together the networks and coalitions, as to do so requires certain changes in approach, behaviour, and expectations to meet customer demands that are different to those of a manufactured product. Research by BSI has identified the demand for a good practice document that would create a common vocabulary to aid procurement, and the identification of what excellence in the delivery of these services looks like.

Draft scopes for each of these PASs are given at Annex 5.

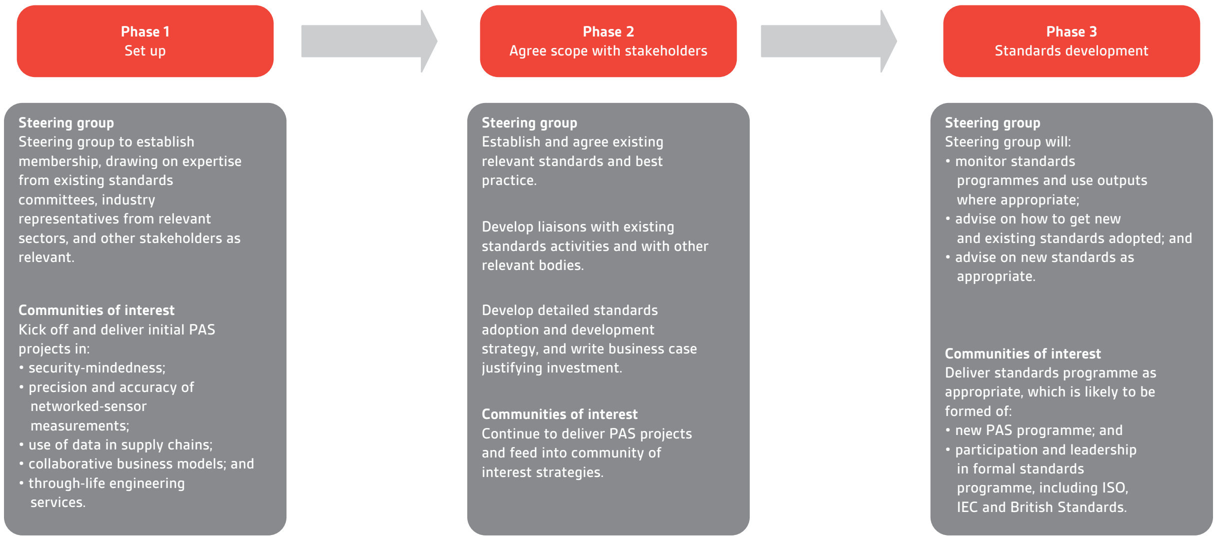
18 See The Economist Intelligence Unit (2014). *Manufacturing and the data conundrum. Too much? Too little? Or just right? A report by the Economist Intelligence Unit*. Available from: https://www.eiuperspectives.economist.com/sites/default/files/Manufacturing_Data_Conundrum_Jul14.pdf

3.4 Timescales and resources

The implementation of the standards programme proposed in this report will follow the process set out in Figure 3. Estimated timescales from programme initiation are set out as follows, with the delivery of the standards programme lasting for as long at the platform[19] exists.

- Establish steering group membership and initiate initial PAS projects **3 months**.
- Develop standards adoption and development strategy **6 months**.
- Delivery of standards programme **Ongoing**.

Figure 3 – Standards programme process



*A PAS is a BSI fast-track consensus-based standardization document.

3.5 Links with HVMC lighthouse model

The HVMC have undertaken their own studies into the role of digital technology adoption and its impact on manufacturing value chains (the lighthouse model). This has identified the following immediate opportunities in the pharma, aerospace, automotive, and food and drink industries:

- collaboration across value chains;
- dynamic value chains;
- product co-creation;
- manufacturing driven design;
- design certification based on digital models;
- environmental and process control;
- dynamic scheduling (logistics and capacity);
- flexible manufacturing;
- assisted manufacturing;
- knowledge capture and management;

19 In this case, the platform refers to any set of parallel national activities that take place to encourage the take-up and growth of digital manufacturing in the UK.

- through-life engineering services; and
- tracking, traceability and product digitization.

There are significant overlaps between the the lighthouse model opportunities and the priority challenges identified in this report, and they are set out as follows (see Table 2).

- Design for digital relates to any legal metrology organization (LMO) that directly relates to design or new manufacturing processes, or provides a different source of data for design, such as knowledge capture and management.
- Simulation, verification and validation is relevant to any LMO that uses, or could use, modelling to replace and/or speed up certain processes.
- Intelligent data gathering and analysis is central to any activity where companies collaborate and share data, acquire data from other sources, or supply data in new ways.
- Rights management, data governance and security is key whenever machines and/or companies are digitally connected.
- Equipment plug and play, capability, and discovery is relevant to all LMOs where machines are digitally connected.

Table 2 – Relationship between priority challenges and HVMC lighthouse model opportunities

Priority challenge / **Lighthouse model opportunity**	**Design for digital (including through-life)**	**Simulation verification and validation**	**Intelligent data gathering and analysis**	**Rights management, data governance and security**	**Equipment plug and play, capability and discovery**
Collaboration across value chains	✓	✓	✓	✓	–
Dynamic value chains	✓	–	✓	✓	✓
Product co-creation	✓	–	–	✓	✓
Manufacturing-driven design	✓	✓	–	–	–
Design certification based on digital models	✓	✓	–	✓	–
Environmental and process control	–	–	✓	✓	✓
Dynamic scheduling (logistics and capacity)	–	–	✓	✓	✓
Flexible manufacturing	✓	–	✓	✓	✓
Assisted manufacturing	✓	✓	–	✓	✓
Knowledge capture and management	✓	–	✓	✓	–
Through-life engineering services	✓	–	✓	✓	✓
Tracking, traceability and product digitization	–	–	✓	✓	✓

Annex 1 – Domain research methodology

A1.1 Objective

This domain research[20] aimed to identify existing formal standards and selected industry documents in the area of digital manufacturing, in an agreed list of countries and standards development organizations (SDOs) which are listed as follows.

- **Globally** – USA (ANSI, API, ASME, ASTM, AWS), Canada (CA), China (CN), Japan (JP) and Korea (KR).
- **EU countries** – Denmark (DK), Finland (FI), France (FA), Germany (DE), Italy (IT), Norway (NO), Sweden (SE) and the United Kingdom (GB).
- **International and European SDOs** – ISO, CEN/CENELEC and ETSI.

The research was not intended to identify legislation.

A1.2 Resources

The following standards databases were used for this piece of research:

- **Perinorm**

  Perinorm is a bibliographic standards reference database, which indexes worldwide standards. All the countries specified in a separate Word document (see **A1.1**) are represented, but publications from more informal bodies are limited. It does not include India, for example.
- **IHS Standards Expert**

  IHS Standards Expert is a standards reference database, which allows the searching of full text for some standards bodies including India, but only keywords or titles.

  IHS Standards Expert does not have a 'keyword in context' function, so we are not able to see where search terms appear in the documents (except for BSI publications which we have full access to on the system).

  If needed, additional searches can be conducted at a later stage using this database, however the results would not be able to be merged with the ones from 'Perinorm' as the information it provides is limited, only document identifier (standard number) and title.

Additionally, two publically available BSI sites have been particularly useful to find new proposals or standards in development where relevant:

- **BSI New Proposals site**

  http://standardsproposals.bsigroup.com/
- **BSI Draft Review system**

  https://drafts.bsigroup.com/

A1.3 Research Methodology

For the purpose of the overall project, a desk based research exercise was conducted using the standards databases specified in Section 2 Resources of this report (see **A1.2**).

20 The domain research was conducted by an information professional working in the BSI Knowledge Centre. The BSI Knowledge Centre is a team of information specialists who provide information for customers on standards content and standardization. The team also provide a bespoke research service where they can identify relevant standards on a topic as well as other industry information including legislation.

The following tasks have been carried out.

1) Extraction of relevant standards that are referenced in the following two freely available reports:
   - *NISTIR 8107. Current Standards Landscape for Smart Manufacturing Systems. Yan Lu, KC Morris and S Frechette. 23 February 2016*
     https://www.nist.gov/node/785831
   - *German Standardisation Roadmap Industry 4.0. Version 2. January 2016*
     http://www.din.de/en/din-and-our-partners/press/press-releases/updated-german-standardization-roadmap-on-industry-4-0-110576
2) Dissemination of information included in relevant reports to both the digital manufacturing and *Industry 4.0*. emerging areas. They majority of these reports have been provided by the Institute for Manufacturing (IfM).
3) Selection and extraction of relevant key terms and phrases from the reports provided by IfM, as well as from various relevant websites of organizations that play an important part in the digital manufacturing world.

   It is worth mentioning that IfM also provided a list of keywords. Only the most relevant and specific ones to digital manufacturing as a concept have been taken into consideration.
4) Creation of a template, in Excel format, which has helped to record and present the standards results in a systematic and structured way.
5) Development of a 'keyword strategy' with a view to retrieve relevant standards to digital manufacturing. This involved:
   - making small groups of homogenous terms or phrases;
   - looking for synonyms;
   - creating logical combinations of keywords and phrases; and
   - refining generic terms by combining them with specific terms such as 'manufacturing' or 'production'.
6) Finally, several keyword searches and combinations of both were performed on our standards databases using the selected terms and phrases listed in the following section (**A1.4**).

A1.4 Keywords

3D CAD
'IoT' OR 'Internet of Things' OR 'Enterprise IoT'
'M2M' OR 'machine-to-machine'
3D printing
3D scanning
Additive Manufacturing
Advanced and autonomous robotics
Advanced and functional materials
Advanced manufacturing
Advanced processing
Artificial intelligence
Augmented reality (AR)
Automotive original equipment manufacturer (OEM)

Big data and knowledge-based automation
Big data forecasting
Business forecasting and algorithm
CAD engineering services
Cloud-Based Design (CBD)
Cloud-Based Manufacturing (CBM)
Commerce OR shopping OR Sale*) AND real-time
company-wide system that integrates analysis, sourcing, contracts etc.
Computer-aided design (CAD)
Computer-aided engineering (CAE)
Computer-aided manufacturing (CAM)
Computerised manufacturing execution systems (MES)
Data in a manufacturing context
Digital avatar
Digital twins
Digitisation of manufacturing processes
Electronic data interchange (EDI)
Enterprise resource planning (ERP)
genetic algorithms
Industrial automation system
Industrial revolution
Information and communications technology (ICT)
Interconnectivity
Manufacturing execution systems (MES)
Order management
Process Simulation
Product data management (PDM)
Product lifecycle management (SLM)
Rapid manufacturing
Rapid Prototyping
Real-time sensor data
Reverse Engineering
Robots OR Robotics
Sensors
Supply chain OR Supply networks
Three-dimensional (3D) visualization
Virtual manufacturing
Virtual manufacturing
Virtual simulation

A1.5 Classification system

Each standard has been classified according to the following four levels, in that order:

1) by source or architecture model;
2) by high-level category;
3) by subcategory; and
4) by keyword search or standard title.

Each individual level is explained as follows.

A1.5.1 Source or architecture model

In order to record and present the results in a logical, structured and systematic way, the following four main groups of results have been specified. Each group relates to the source or architecture model where the standards have been found. The four groups are:

- **Group 1 – BSI model**

  BSI held a workshop in July 2016 on the role of standards and good practice in transforming the way manufacturing sectors operate using digital capabilities. As result 5 priority areas, where action was needed, were highlighted. These are:

  1. interoperability;
  2. use of data in manufacturing supply chains;
  3. governance of manufacturing supply chain data;
  4. performance assurance of 'digital twins'; and
  5. highly collaborative operational and business models.

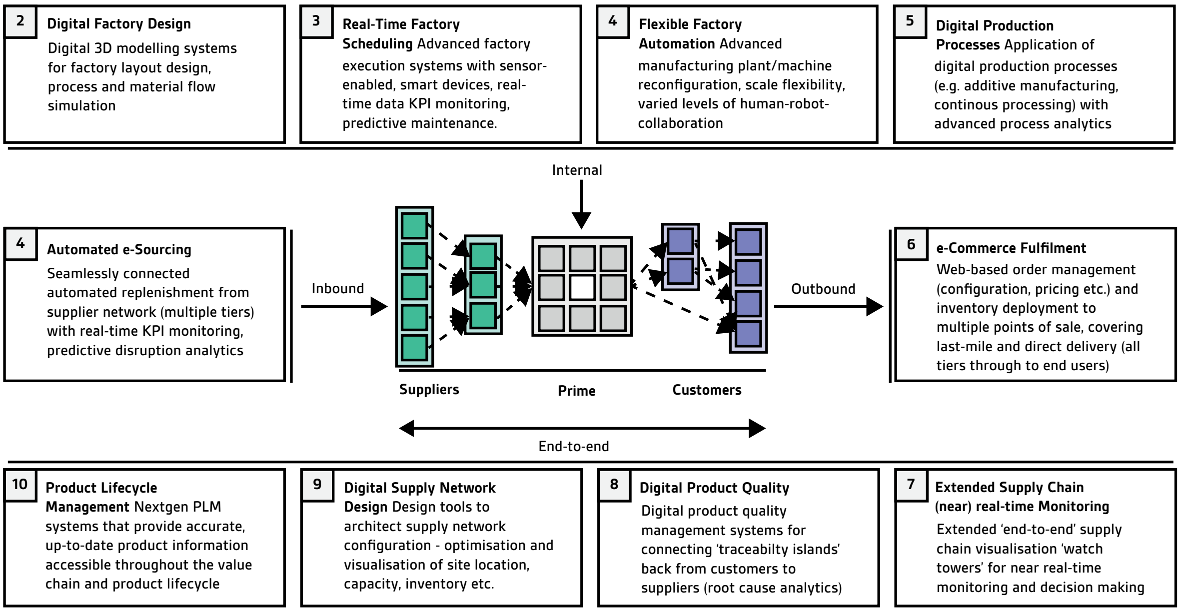
  This group of results includes standards that have come up as result of keyword searches performed under each of the five priority areas above.

- **Group 2 – IfM scenarios**

  BSI and the Institute for Manufacturing (IfM) recently established the main benefits and opportunities arising from digitally connecting supply chains end-to-end throughout the life of the product, and this would also have profound implications for improved design. This work is set out in the IfM document, *Application of Digital technologies to Innovation in Manufacturing*, draft final report, 23 August 2016.

  It identified the 10 different scenarios where generic manufacturing supply chains will adopt digital technologies, and also established that this would give rise to customer-centric flexible manufacturing, mass customization and value chain optimization.

  The standards listed in this group are the result of keyword searches applicable to each of the 10 scenarios included in the diagram below:



Source: University of Cambridge Institute for Manufacturing, Centre for International Manufacturing Research (Dr. Jag Srai et. al.)

- **Group 3 – DIN (Industry 4.0)**

  In this group, no keyword searches were conducted. Instead, all referenced standards in the *German Standardisation Roadmap Industry 4.0. Version 2* were extracted and allocated under this group.

- **Group 4 – American (NIST)**

  Group 4 includes all standards that are referenced in the NISTIR 8107 report - *Current Standards Landscape for Smart Manufacturing Systems.*

A1.6 High-level categories

For ease of analysis of the data, the following classification system has been created.

There are 5 high-level categories which represent the type of standard, whether is a standard for the design of a product, for logistics or for the production process, etc.

1. Product Design
2. Production
3. Logistics
4. Through-life and End-of-life
5. End-to-end connected networks

A1.7 Sub-categories

A list of more specific categories has been assigned to each of the five high-level categories above. The sub-categories were chosen according to the standards that were found for each of the four sources / architecture models specified in **A1.5.1**.

The following grid includes all groups and high-level categories and subcategories. Where 'n/a' has been applied, no standards have been retrieved for that type of standard (high-level category) under the particular source or architecture model.

Digital manufacturing standards – classification system

		Source/Model (where standards ahve been found)			
		BSI Model	IfM scenarios	DIN (Industry 4.0)	American (NIST)
High-level categories & subcategories	Product Design	'Performance assurance of digital twins'	n/a	n/a	'General standards for modelling AND executing business processes' 'Modelling practice' 'Product Model and Data Exchange'
	Production	'Interoperability' 'Automation systems and integration'	'Digital factory design' 'Digital production processes' 'Flexible factory automation' 'Real time factory'	'Additive manufacturing' 'Automation' 'Programmable electronic safety-related systems' 'Instrumented systems for the process industry sector' 'Machinery' 'Reliability and maintainability' 'Smart Energy'	'Production lifecycle data management' 'Systems engineering' 'System modelling' 'O&M standards' 'Manufacturing Model Data'
	Logistics	'Governance of manufacturing supply chain data' 'Use of data in manufacturing supply chains'	'Automated e-sourcing' 'E-commerce fulfilment' 'Digital supply network design' 'Extended supply chain monitoring'	n/a	n/a
	Through-life and End-of-life	'Collaborative operational & business models'	'Product lifecycle management'	n/a	n/a
	End-to-end connected networks	n/a	'Digital product quality'	'Communications' 'Data sets for libraries' 'Devices and integration in enterprise systems' 'information Technology' 'industrial communication networks' 'Industrial process measurement and control' 'International Electrotechnical Vocabulary' 'Radio-based communication' 'Radio technologies' 'Software and Systems Engineering' 'Telecommunications and information exghange between systems'	'Cross-level' 'Enterprise level' 'MoM-level' 'Scada & device level'

A1.8 Keyword searches

BSI model

Logistics
(Governance OR 'risk management') AND Manufacturing
(manufacturing OR engineering) AND (data OR communication*)
Data AND (Governance OR 'risk management')
Governance AND 'supply chain'
Product Design
'Digital twin*'
'M2M' OR 'machine-to-machine'
(3D OR three-dimensional) AND model*
Avatar OR Real-time AND manufacturing
IoT OR 'Internet of Things' OR 'Enterprise IoT'
Product lifecycle management (PLM or SLM)
Production
(manufacturing OR engineering) AND (data OR communication*)
Interoperability AND (Manufact* OR automat*)
Through-life and End-of-life
SVS/1/4 - Collaborative business relationships

IfM Scenarios

End-to-end connected networks
Digital Product Quality
'Problem Solving'
'Product Quality'
Digital Product* Quality
Root cause analysis OR 'Root cause analytics' OR RCA
Tracebility islands'
Logistics
Automated e-sourcing
'Enterprise resource planning'
'e-sourcing'
(Cloud OR Web) AND ('Supply Chain Management' OR SCM)
Big Data
Connected automated replenishment
Data Analytics AND (Manufacturing OR production)
Dynamc forecasting AND (Manufacturing OR production)
Predictive disruption analytics
System* integration AND (analysis, sourcing, contract*)
Digital Supply Network Design
'Supply Network*' AND (Design OR visualization)
Algorithm* AND network*
Digital AND 'Supply Network*'
Optimisation* AND (site location OR capacity OR inventory)
e-Commerce fulfilment
'Big data' forecast*
'Electronic data interchange' OR EDI
'Inventory management system*'
(Commerce OR shopping OR Sale*) AND real-time
(Inventory OR stock) AND ('Electronic Data' OR web OR real-time)
Business AND (forecasting OR algorithm*)
e-Commerce OR 'online shopping' OR 'online marketplace*'
Forecast* customer* demand
Order Management
Extended Supply Chain (near real-time Monitoring)
'Extended supply chain'
'Load balancing'
'Real-time' AND 'Risk management'
'Resource optimisation'
'Supply Chain' AND 'End-to-end'

'Track-and-trace' 'Supply Chain' AND 'real-time' Data AND ('management' OR analy* OR integration OR shar*) AND 'supply chain' Data AND (security OR sovereignty) AND 'supply chain'
Production
Digital Factory Design 'Digital factory' 'Process Simulation' (Three-dimensional OR 3D OR CAD) AND (Visualisation OR Manufacturing OR Production) **Digital Production Processes** 'Additive manufacturing' (incl. 'rapid manufacturing) 'Advanced process' AND (Analysis OR Analytics) 'Computer-aided manufacturing' OR 'CAM' 'Continuous processing' 'Reverse engineering' OR 'back engineering' ('Computer-aided engineering' OR CAE) AND Manufacturing ('Computerized manufacturing execution' OR MES) AND System* (3D OR 'Three-dimensional') AND printing Digital AND (production OR manufact*) Digitisation of manufacturing Processes Rapid prototyping Virtual manufacturing **Flexible Factory Automation** 'Advanced manufacturing' 'Advanced processing' 'Graphical user interface' OR 'GUI' (Automation OR Automated) AND manufacturing Accounts Receivable Automation Factory Automation Robot* AND Manufact* **Real-time Factory** 'manufacturing execution systems' 'Real-time Factory' Algorithm* AND (factory OR manufacturing OR production) Predictive maintenance Real-time AND (industrial OR automation) Real-time data monitor* Sensor* AND (enabled OR Network*) Sensor* AND (factory OR manufacturing OR production) Smart device* AND (factory OR manufacturing OR production)

Through-life and End-of-life
Product Lifecycle Management
'Product Lifecycle' OR PLM
'idea-to-end'
Fast data AND (cleansing OR maintenance)

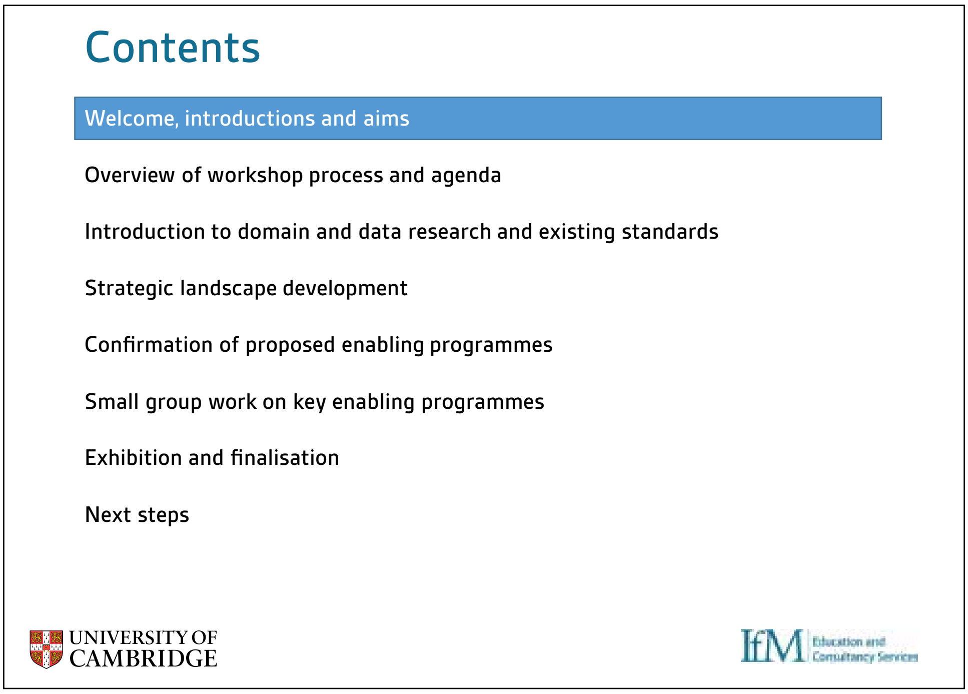
A1.9 Limitations

The limitations of the project result largely from aspects of the process that fall outside of the control of the Knowledge Centre. Due to the subject matter in question and being a new emerging area, it was not possible to identify absolutely every standard, guidance, initiative or piece of information with relevance to the digital manufacturing industry. Some existing initiatives and ideas might have not been made public yet.

It is worth noting that the author of the report is an information professional working in the BSI Knowledge Centre. The team has experience of researching the global standards landscape by using databases and web searches with pre-determined search criteria, and has no subject specialism in the digital manufacturing area specifically. The Knowledge Centre relies on technical experts for the analysis of the data that they provide and therefore are unable to provide interpretation of their standards research. However, they can provide findings based on factual information and can identify trends in the data.

To validate the results from this research and contextualize them within specific industries, an effective market engagement exercise is recommended. This will hopefully add some real context to the research carried out by highlighting which standards are actually used by industry and to identify areas for further research.

Annex 2 – Industry workshop methodology



Workshop objective

To contribute to and validate the BSI domain research and draft work programmes:

- Develop a strategic landscape for standards in support of Digital Manufacturing
- Identify a vision for standards in support of Digital Manufacturing
- Agree enabling programmes required to support the vision
- Develop 'business cases' for the enabling programmes feeding into the proposed communities of interest

The workshop output will be analysed following the workshop to examine alignment or otherwise with the BSI domain research

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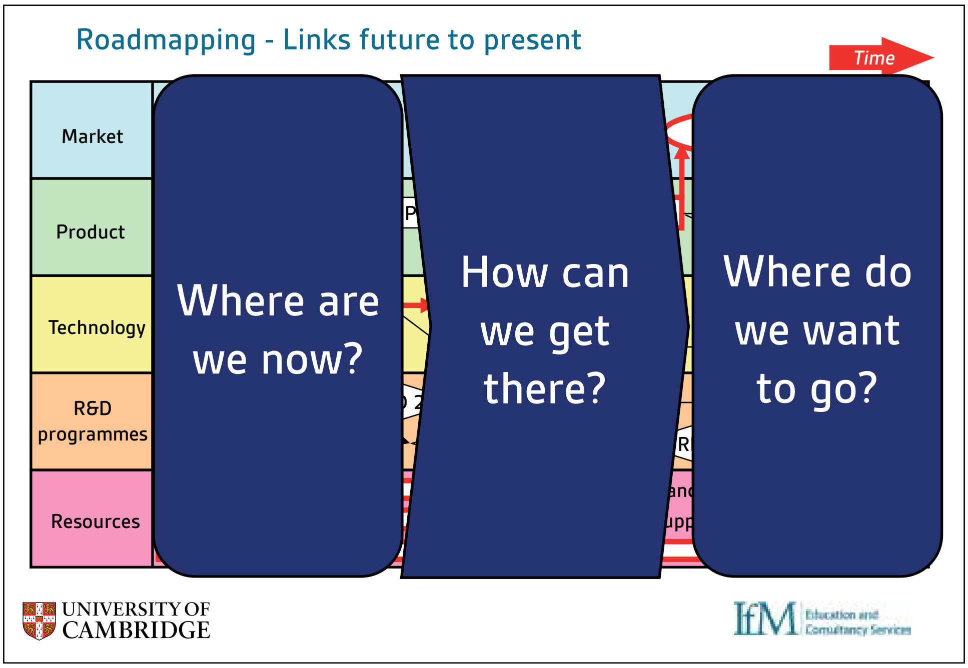

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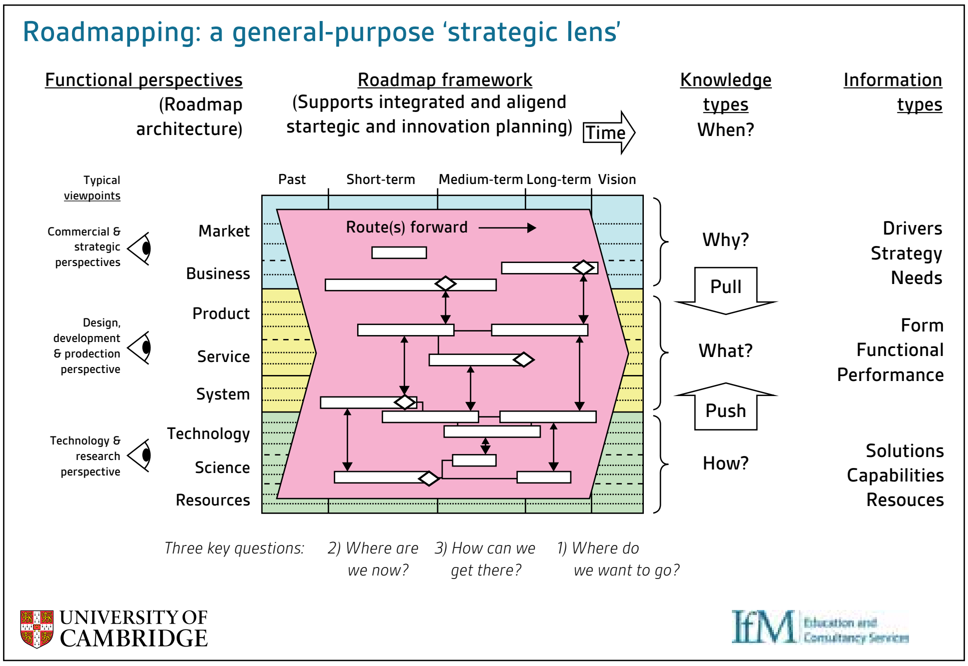

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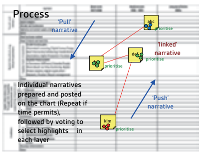
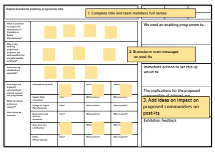
Workshop outline

Morning



1. Outline process and agenda
2. High level presentation of emerging findings and current standards
3. Landscape development
4. Develop candidate list of proposed enabling programmes (combining overlaps/repeats and select for pm development)

Afternoon



5. Small group work on business cases for the proposed enabling programmes
6. Plenary review of business cases
7. Business case finalisation and feedback

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Agenda

Time	Topic
09:00	• Arrival, registration and refreshments
09:30	• Welcome, introductions and aims • Overview of workshop process and agenda • Introduction to domain and data research and existing standards
10:15	• Refreshment break
10:30	• Plenary activity to develop the strategic landscape. See the further description below
12:30	• Lunch (Review of landscape priorities to identify proposed enabling programmes)
13:15	• Confirmation of proposed enabling programmes to be developed in further detail • Small group work on key enabling programmes using business case templates (See further description below)
14:45	• Plenary exhibition style presentation of business cases with feedback, discussion and questions
15:15	• Business case finalisation
15:30	• Plenary feedback
16:00	• Next steps and close

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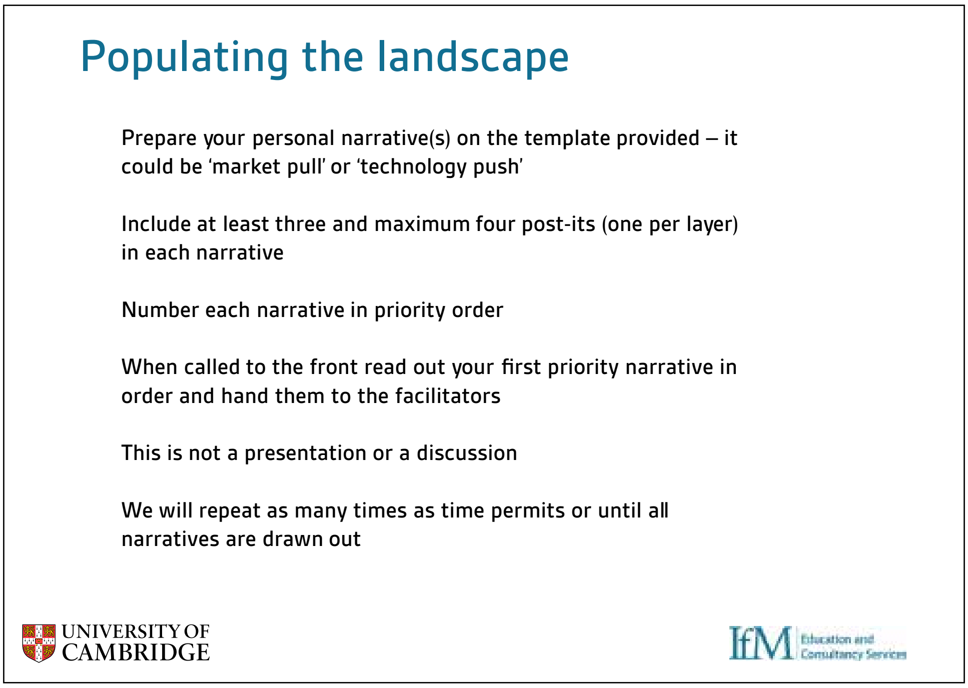
Populating the landscape
Prepare your personal narrative(s) on the template provided – it could be 'market pull' or 'technology push'
Include at least three and maximum four post-its (one per layer) in each narrative
Number each narrative in priority order
When called to the front read out your first priority narrative in order and hand them to the facilitators
This is not a presentation or a discussion
We will repeat as many times as time permits or until all narratives are drawn out
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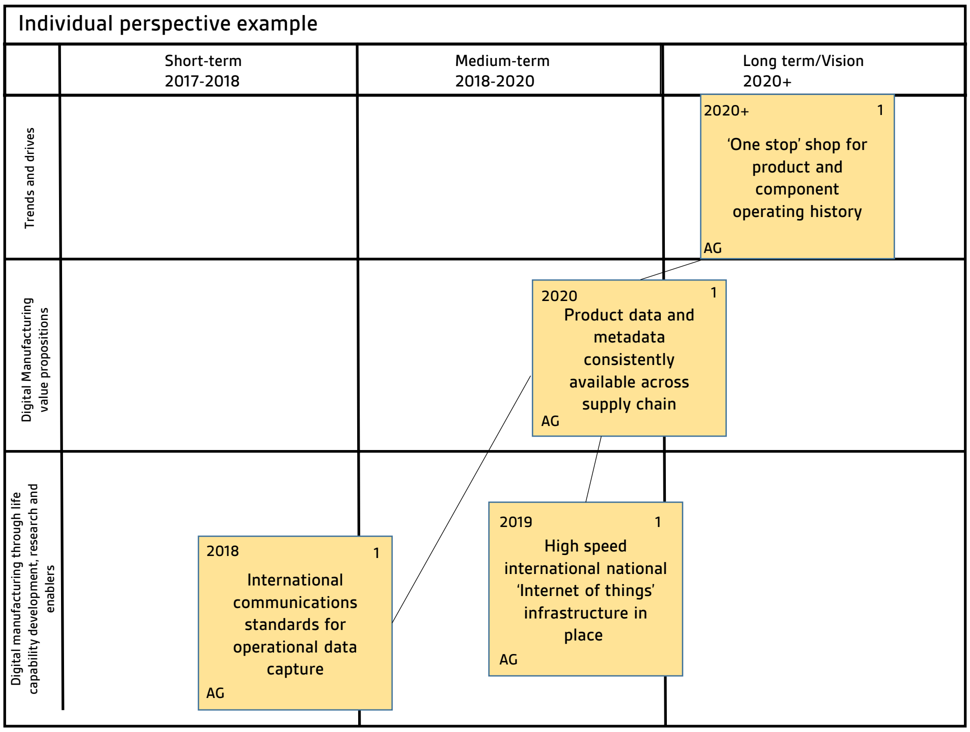
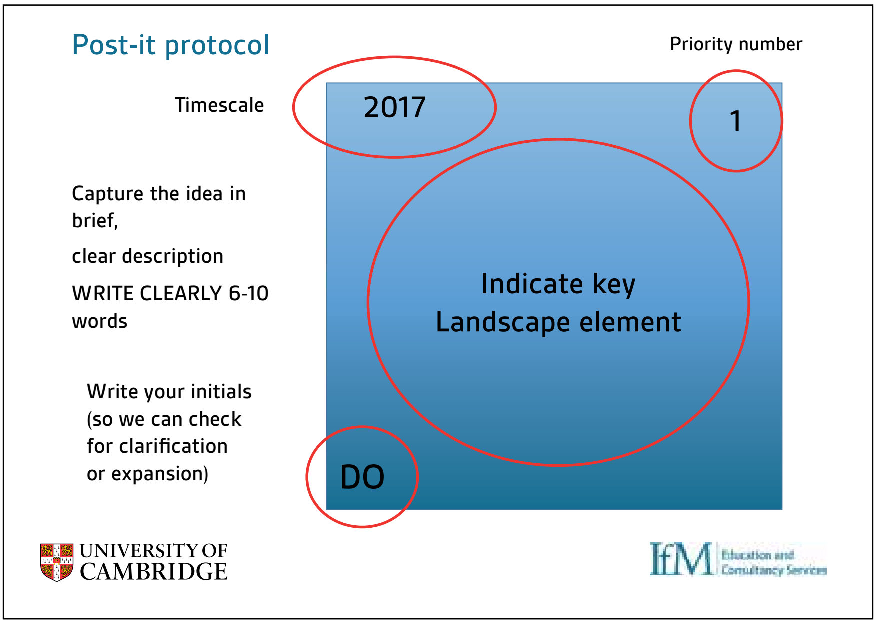

Individual perspective example
Short-term 2017-2018
Medium-term 2018-2020
Long term/Vision 2020+
Trends and drives
Digital Manufacturing value propositions
Digital manufacturing through life capability development, research and enablers
2020+ 1
'One stop' shop for product and component operating history
AG
2020 1
Product data and metadata consistently available across supply chain
AG
2019 1
High speed international national 'Internet of things' infrastructure in place
AG
2018 1
International communications standards for operational data capture
AG



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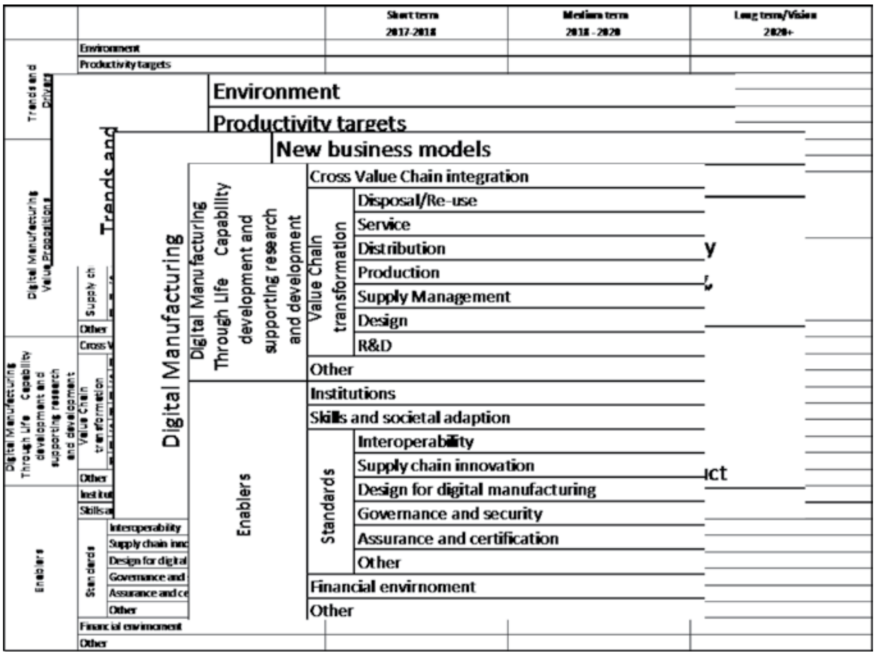

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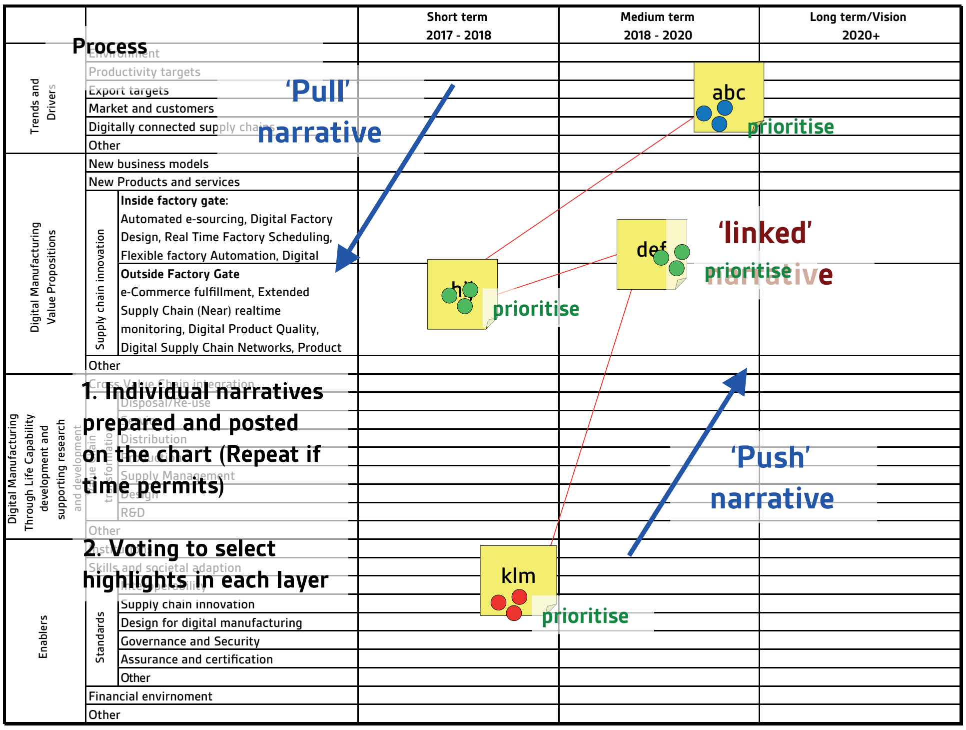

Populating the landscape

Prepare your personal narrative(s) on the template provided –it could be 'market pull' or 'technology push'

Include at least three and maximum four post-its (one per layer) in each narrative

Number each narrative in priority order

When called to the front read out your first priority narrative in order and hand them to the facilitators

This is not a presentation or a discussion

We will repeat as many times as time permits or until all narratives are drawn out

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Individual perspective example

	Short term 2017-2018	Medium term 2018-2020	Long term/Vision 2020+
Trends and drives			
Digital Manufacturing value propositions			
Digital manufacturing through life capability development, research and enablers			

Prioritising the landscape

Vote to select the most important elements of the landscape:

- **Four blue dots on those trends and drivers you consider to be the most important**
- **Four green dots for the value propositions you think 'UK plc' will have the most opportunity to add value in digital manufacturing**
- **Four red dots for most important capabilities or enablers you feel are required to deliver your chosen value propositions**

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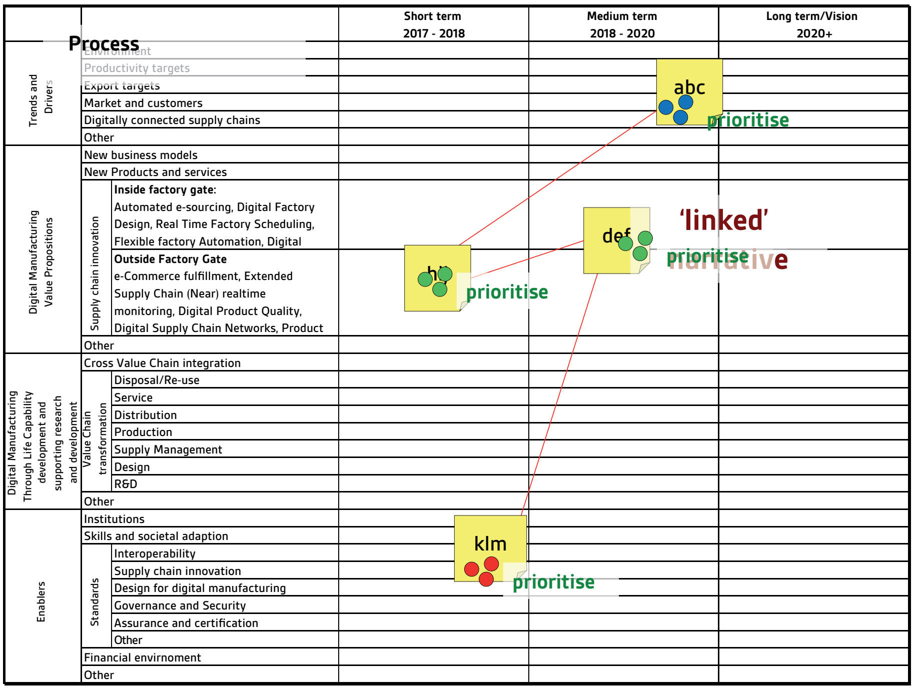

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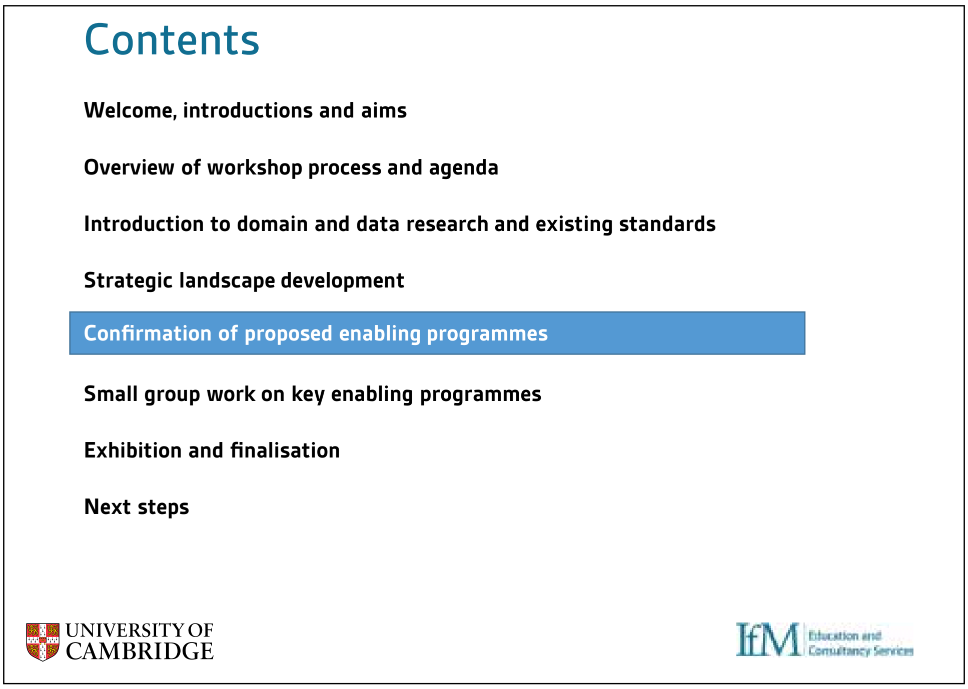

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Confirmation of proposed enabling programmes

Over lunch the facilitators and BSI have examined the landscape details and propose the following enabling programmes for further development

- Digital design transfer and interoperability between digital models (including through life)
- Simulation, verification and validation (Including digital twins and in process modelling)
- Feeding real world sensing back to design
- Intelligent data gathering and analysis
- Rights management, data governance and security
- Equipment plug and play, capability and discovery

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Digital Standards enabling programme title:

What is proposed to support the development of Standards in Digital Manufacturing?				
Why is this enabling programme proposed, and what would be the principle benefits to 'UK plc'?				
What existing standards are applicable?				
How might the proposed communities of interest, support this programme? What immediate actions are required? Who should be involved?	Interoperability:	How?	What actions?	Who involved?
	Supply Chain innovation:	How?	What actions?	Who involved?
	Design for Digital Manufacturing:	How?	What actions?	Who involved?
	Governance and Security standards:	How?	What actions?	Who involved?
	Assurance and certification:	How?	What actions?	Who involved?
	Other (Please specify):	How?	What actions?	Who involved?

Team:		

We need an enabling programme to…
We should do this because…
Immediate actions to set this up would be…
The implications for the proposed communities of interest are…
Exhibition feedback

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Topic Roadmap and capability business case development

75 minutes

- Nominated teams review their allocated topic using the business case template provided
  1. Complete title and team members full names
  2. Brainstorm main messages on post-its
  3. Add ideas on impact on proposed communities on post-its
  4. Discuss and agree main messages and impact on proposed communities of practice, remove the post-its and complete the chart long hand
  5. Complete 'elevator pitch' summary long hand, leaving feedback box empty
- Write neatly as these will be reviewed 'exhibition' style

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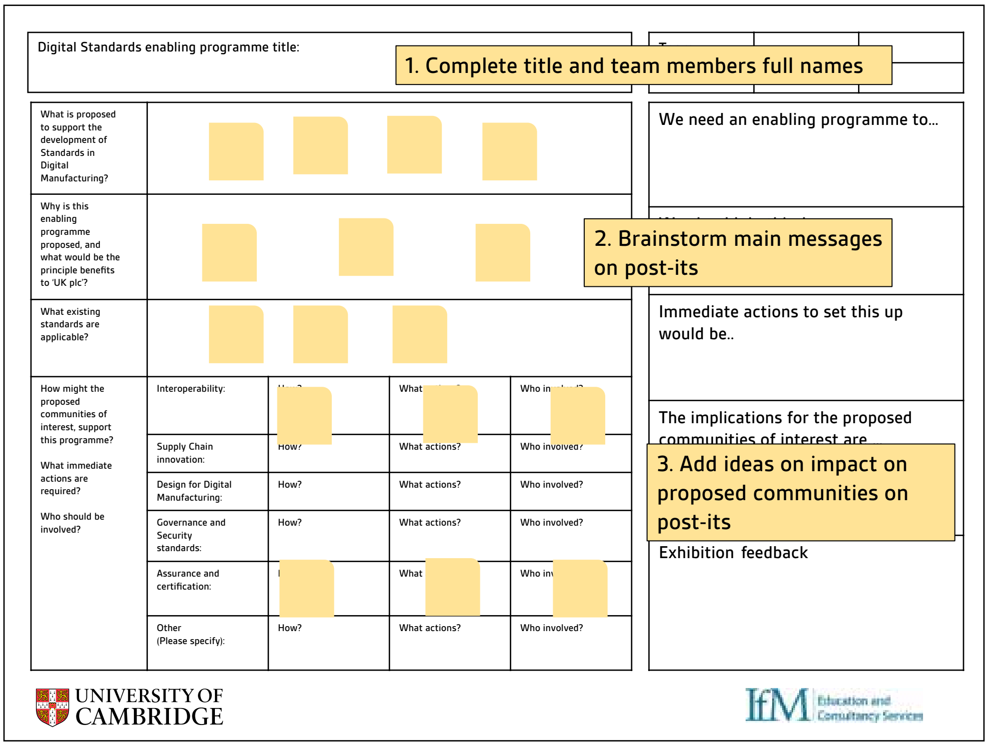

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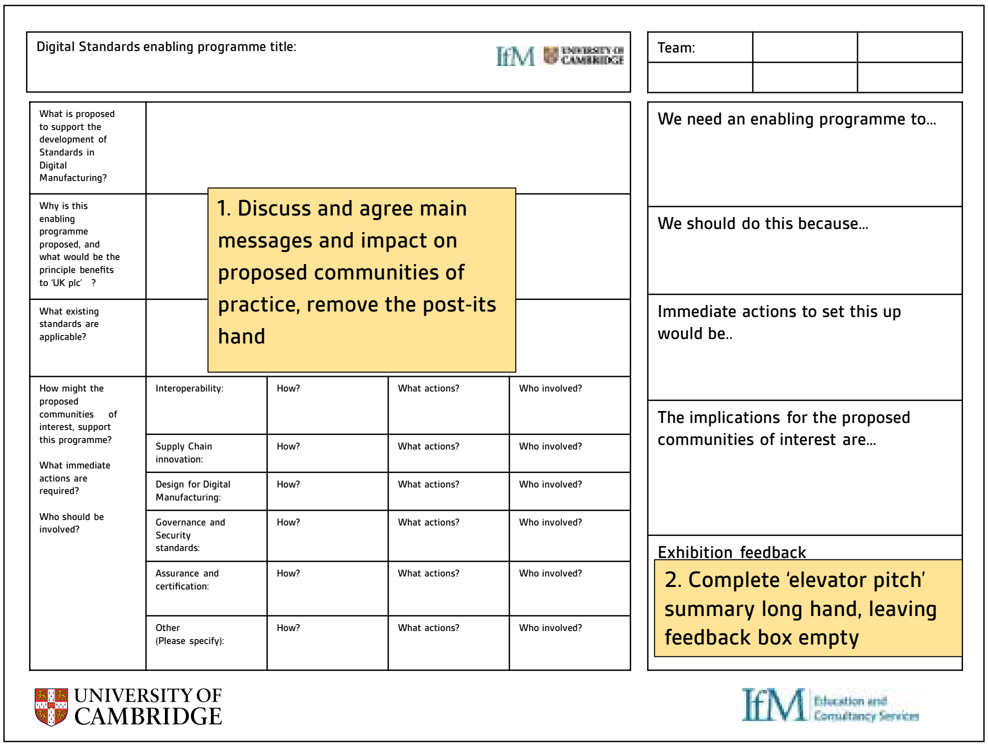

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Digital Standards enabling programme title:					Team:		

What is proposed to support the development of Standards in Digital Manufacturing?				
Why is this enabling programme proposed, and what would be the principle benefits to 'UK plc'?				
What existing standards are applicable?				
How might the proposed communities of interest, support this programme? What immediate actions are required? Who should be involved?	Interoperability:	How?	What actions?	Who involved?
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	Design for Digital Manufacturing:	How?	What actions?	Who involved?
	Governance and Security standards:	How?	What actions?	Who involved?
	Assurance and certification:	How?	What actions?	Who involved?
	Other (Please specify):	How?	What actions?	Who involved?

We need an enabling programme to…

We should do this because…

Immediate actions to set this up would be…

The implications for the proposed communities of interest are…

Exhibition feedback

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Plenary Review and programme finalisation

30 minutes plenary

- 'Exhibition style' review of business case templates
- Go to the topics you feel you know most about and make comments / review using shaped post-its (there is a box for general feedback)
- Don't worry if you don't get around them all...
- Teams will use your input in the next stage of the workshop.

15 minutes in teams
- Review feedback and finalize key messages

1 minute per team x 10 teams (20 minutes allowed including discussion)

- Summarise key messages and feedback response from business case

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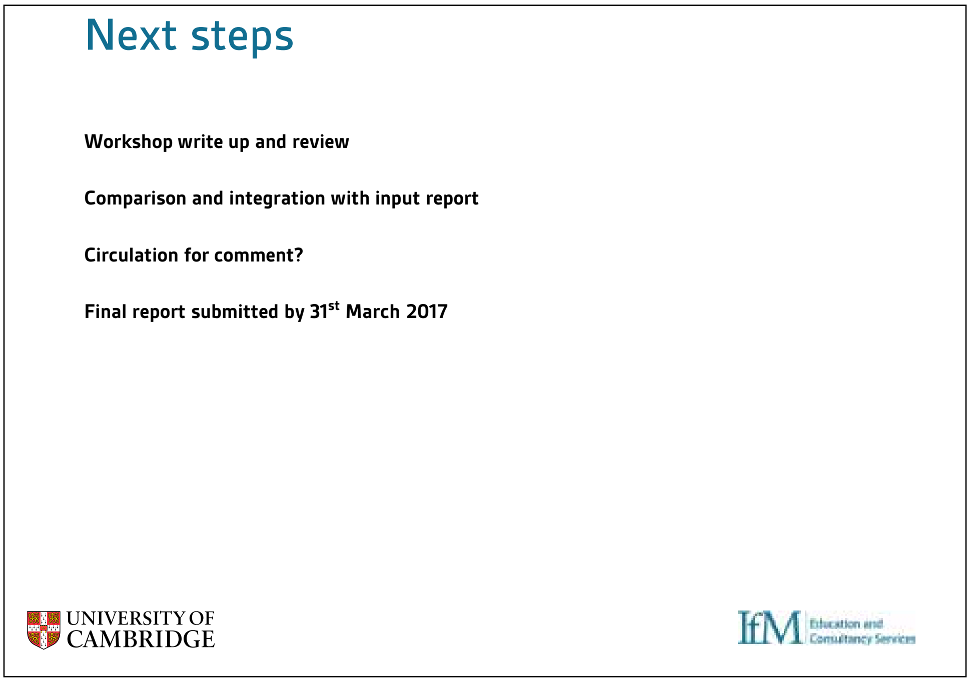
Next steps
Workshop write up and review
Comparison and integration with input report
Circulation for comment?
Final report submitted by 31st March 2017
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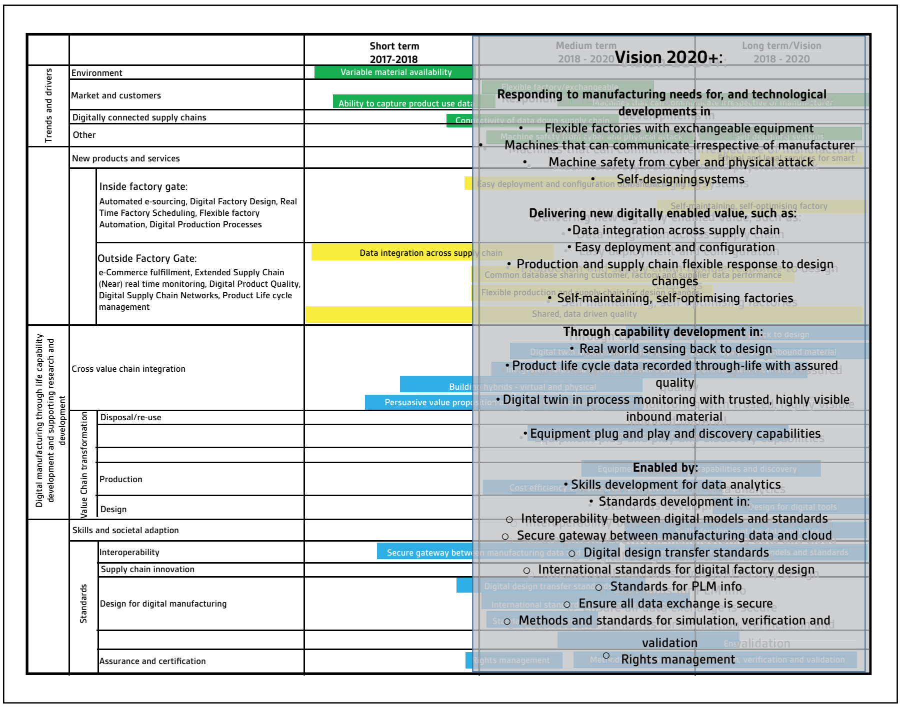
Annex 3 – Industry workshop outputs



Trends and drivers

Swim lane	Title	Date	Votes
Environment	Variable material availability	2017	5
Market and customers	Flexible factory/exchangeable equipment	2018-2020	12
	Machines that can communicate irrespective of manufacturer	2020+	6
	Ability to capture product use data	2017-2018	4
Digitally connected supply chains	Connectivity of data down suply chain	2018	11
Other	Machine safety from cyber and physical attack	2018-2020	6
Other	Self designing systems	2020	5

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Value propositions

Swim lane	Title	Date	Votes
New Products and services	Ethical and legal services for smart factory	2020	3
Supply chain innovation: Inside factory gate	Easy deployment and configuration of manufacturing ICT	2019	9
	Self-maintaining, self-optimizing factory	2020+	3
Supply chain innovation: Outside factory gate	Data integration across supply chain	2017-2019	10
	Common database sharing customer, factory and supplier data performance	2018	6
	Flexible production and supply chain for design changes	2018-2019	5
	Shared, data driven quality	TBC	5
	Accessibility for all parts of supply chain	2017	4

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Capabilities and enablers

	Swim lane	Title	Date	Votes
Capabilities	Cross Value Chain integration	Real world sensing back to design	2020	6
		Digital twin in process monitoring with trusted, highly visible inbound material	TBC	6
	In service	Product life cycle data recorded through with assured quality	2019	2
	Production	Equipment plug and play capabilities and discovery	2020	2
Enablers	Skills and societal adaption	Skills development for data analytics	2020	6
	Standards: Interoperability	Interoperability between digital models and standards	2020+	6
		Secure gateway between manufacturing data and cloud	2018	4
	Standards: Design for digital manufacturing	Digital design transfer standards	2018	7
		International standards for digital factory design	2018-2020	4
		Standards for PLM info	2018	4
	Standards: Governance and security	Ensure all data exchange is secure	2020	4
	Standards: Assurance and certification	Methods and standards for simulation, verification and validation	2020+	8
		Rights management	2018	5

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Annex 4 – Industry workshop attendees by type of organization

The industry workshop held on 23 February 2017 was attended by 29 stakeholders, listed below by stakeholder type.

- Academic and research (8)
- Consultancy (7)
- Manufacturer (9)
- Software company (1)
- Standards body (3)
- Trade association (1)

Annex 5 – Draft PAS scopes

One of the deliverables of this project is to identify the scopes of the first standards that need to be delivered as part of the UK efforts to promote digital manufacturing technology adoption in the UK. The draft PAS scopes are as follows.

- **Digital manufacturing – Guide to the use of data in manufacturing supply chains**

  This PAS gives guidance on the use of data in manufacturing supply chains. It covers how companies can extract more value from data that is bigger in volume, from a wide variety of sources, is fast moving, and often of unknown provenance.

  It is for use by manufacturing companies operating within a supply chain.

- **Digital manufacturing – Guide to establishing a framework for collaborative relationships in supply chains**

  This PAS gives guidance on how manufacturing companies within a supply chain can transform their relationships and business models away from a transactional model towards one that puts quickly meeting customer needs at the heart of the partnership.

  It is for use by manufacturing companies operating within a supply chain.

- **Digital manufacturing – Specification for security-minded management**

  This PAS specifies requirements for the security-minded management of digital manufacturing processes. It outlines security threats to information at all stages of the product lifecycle.

  This PAS addresses the steps required to create and cultivate an appropriate safety and security mindset and culture across many partners, including the need to monitor and audit compliance.

  It is for use by manufacturing companies looking to adopt digital capabilities, and also digital companies looking to offer service into the manufacturing value chain.

- **Digital Manufacturing – Guide to establishing the precision and accuracy of connected sensor measurements in a network**

  This PAS gives guidance on establishing the precision and accuracy of data captured by connected sensors in a network.

  It aims to establish good practice for developers and users of sensor network technologies and promote to the use of sensor network data.

- **Digital manufacturing – Vocabulary for the design and delivery of through-life engineering services**

  This PAS defines terms for through-life engineering services. It aims to provide clarity to all actors within a supply network that is looking to provide innovative services in a traditionally manufacturing environment.

  It is for use by all companies, including end users, within an engineering service supply network.

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