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Strategic Research & Innovation Roadmap and Business Opportunities for ICT in Manufacturing

Road4FAME

SEVENTH FRAMEWORK PROGRAMME

Steinbeis-Edition

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Road4FAME has received funding from the European Commission's 7th Framework Programme under grant agreement no. 609167 and is part of the Factories of the Future PPP. The Consortium thanks the responsible Project Officer from the European Commission Dr Rolf Riemenschneider and the Project Reviewers Franz-Josef Stewing and Uros Janko for the very fruitful collaboration.

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1st edition, 2015 | Steinbeis-Edition, Stuttgart
ISBN 978-3-95663-064-4

Layout: Steinbeis-Europa-Zentrum Karlsruhe
Cover picture: ©Rainer Plendl – Fotolia.com
Production: Frick Kreativbüro & Onlinedruckerei e.K., Krumbach

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181138-2015-10 | www.steinbeis-edition.de

Content

Introduction

The Road4FAME project has developed a strategic research and innovation roadmap for IT architectures and services in manufacturing. The project 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. The key aims were to align future ICT (information and communication technology) research with the needs of European manufacturing businesses, and to provide European manufacturing businesses with a reference against which they can derive innovation strategies and identify novel business opportunities.

ICT Solutions

Eleven ICT solutions were identified and evaluated with respect to their ability to provide support for current manufacturing trends and drivers. Critically the aim is to assist European manufacturing companies optimise their business operations, remain competitive, maximise the value they get from their networks and utilize existing and future ICT systems to improve operations.

Strategic Vision for the Future

The Road4FAME vision contains a future where companies come together as virtual enterprises comprised of associations of companies that cooperate ad-hoc to complement strengths, attain the capacities of large enterprises, gain the ability to react to market opportunities, perform research together, innovate products and minimizes costs and risks for approaching new markets with new products. In this vision large companies may bring capacity, and small companies may bring flexibility and innovation power. Going a step beyond this vision, in the near future manufacturing could be provided as a service (MaaS). Here, there is a need to reconfigure quickly and scale up production at short notice, to establish close information exchange with customers, i.e. integrate with other businesses and enter into business agreements, and cooperate with the new partners in order to fulfil new orders appropriately. Strategically companies will need to anticipate changes in demand using data mining on a variety of data coming from many sources, e.g. social networks.

As customers and companies become more environmentally aware, environmental sustainability will be introduced as a key parameter in all steps of the product life-cycle, including sourcing and recycling. Real-time information about the source of raw materials and the footprint of manufacturing processes will be used to steer production towards minimal environmental impact. The environmental implications of design decisions, process decisions, and buying decisions will become completely transparent allowing a company to promote a “green” image. Looking further into the future new business models based on buyback of products for recycling, or product rental and return for recycle, will become more common.

Finally, the Road4FAME vision sees increased demand for customisation, which could eventually lead to high volume “mass customisation” with short product life cycles. This requires both long-term and ad-hoc cooperation in the supply chain and high levels of automation, short reconfiguration cycles, including tests/experimental production, fast reprogramming of machines and frequent updates of information for more highly skilled and IT literate workers. Supporting this appropriate IT provision is required for the human who is embedded in the digital factory, in the form of context-relevant information and on-the-fly knowledge provision supported by knowledge based decision support systems and self-learning systems.

ICT Innovation in Manufacturing

From the 1970s onwards enterprises have deployed several types of ICT systems falling into two general categories: technology enablers and enterprise business models (Garetti et al 2007). Examples of ICT application, in terms of technology enablers, include:

- In production, using fixed and programmable automation for batch control e.g. numerically controlled (NC) machine tools, e.g. robots and flexible automation, allowing quick changeovers.
- Automation of production lines led to the development of programmable logic controllers (PLCs) for timing and sequencing operations, e.g. automotive machining, press work.
- Automated assemblies, e.g. NC machines producing printed circuit boards (PCBs), robots in manufacturing used for material handling, processing ops, assembly and inspection.
- Flexible Manufacturing Systems (FMS) and flexible automation, using processing machines CNC linked by material handling systems and controlled by a central computer.
- Computing Integrated Manufacturing (CIM) has developed from computer aided design/ computer aided manufacture (CAD/CAM) for part and product specifications, process data storage and display.
- Intelligent Manufacturing – real time based optimisation through the entire value chain.

In terms of support of the enterprise business model, the growth of ICT adoption has been accelerated through the development of microcomputers in the 1980s, the personal computer in the 1990s, and the subsequent rise of the internet. The main areas of ICT application include:

New product development

- Manufacturing planning including inventory control applications and processes, e.g. MRP
- Factory design integration platforms and tools
- Document management systems including tools for sharing information in distributed environments

Looking to the future, the highly flexible process automation world is likely to be driven by data captured by intelligent tags and sensors, and shared across a wireless mesh (Schulz, 2015) to support:

- Multivariate control algorithms that drive the industrial processes to their optimal point and are hungry for live data from the process and from data historians
- Supply chains performing just-in-time deliveries to constantly-changing production lines that need to be kept fully up-to-date
- Dynamic and complex order, delivery and return systems that have to interact closely with production
- Power, cooling, heating and other infrastructure that needs to be fully aware of the client base it is supplying so that the appropriate process automation environment is provided.
- The co-ordination of the entire process by a modular, networked facility automation system

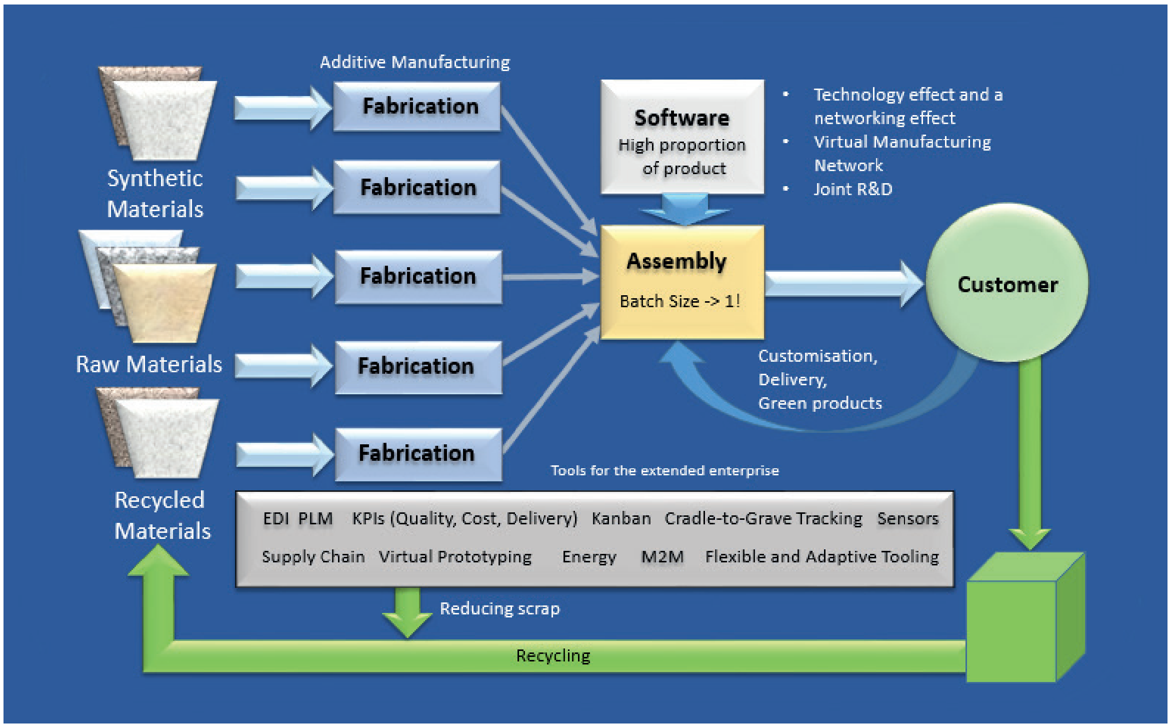


Figure 1: Today's Complex Manufacturing Scenario

The industrial revolution continues, accelerated by digital technologies. ICT-based solutions applied across the manufacturing process chain help to make manufacturing more efficient and sustainable while also allowing the creation of virtual value chains independent of geographical location (Europa 2013).

Traditionally, manufacturing has been defined as the production process whereby raw materials are transformed into useful products and goods. Nowadays, although physical transformation is often at the centre of a wider manufacturing value chain, manufacturing goes beyond production and also encompasses research, design and service provision. Manufacturers are frequently using this wider value chain to generate new and additional revenues.

The world has changed significantly and business customers and consumers alike are increasingly aware of the economic and environmental liability that ownership of a product may entail. There are also a number of alternative sources for products and so value is often seen as more than just ownership. Information and communications technology means that there are many new possibilities in terms of what forms of value can be provided, how it can be provided and by whom, and where activities can take place. Through outsourcing, developing economies present huge, low-cost, international sources of capacity for manufacturing and other inputs such as engineering and R&D.

The current situation in manufacturing is shown in Figure 1. Manufacturers are increasingly becoming assemblers of components which are fabricated in elaborate supply chains. This leads to the concept of virtual manufacturing networks to produce products and more and more companies are performing joint research and development with suppliers. The product may consist of both hardware and software and the batch size for products in many cases is being driven towards more customised products with a batch size of 1. There is an increased linkage with the customer as regards individual preferences. Customers may also have specific delivery demands and may also have a preference for green products. Recycling is also becoming a key concern driven by regulation. There are efforts to reduce scrap within the manufacturing process but also to recycle products which reached end-of-life status.. This adds to the sourcing options for raw materials which may now also come from recycled materials. Here advances in synthetic materials also have a role to play, along with methodologies to reduce scrap and build up material matrices using additive manufacturing. To support all of these changes ICT and software have been introduced to efficiently manage the process within companies and supply chains, monitor KPIs, track components through the process, monitor and optimise energy usage, provide rapid prototyping of new products, and flexible and adaptive manufacturing processes to produce customised products.

In sum, exploiting solutions across the manufacturing process chain that are based on information and communications technology (ICT) is important for:

- making manufacturing more effcient
- allowing more personalized, diversified and at the same time mass-produced product portfolios
- flexible reaction to market changes.

Thus, enabling manufacturers to stay ahead of the competition ensures Europe's overall competitiveness.

Supporting this strategic change the German Industry 4.0 initiative established by major public and private initiatives is promoting the 4th industrial revolution. Figure 2 shows the previous revolutions in manufacturing, which were caused by steam engines, assembly-line work, and electronics and automation. The 4th industrial revolution is based on the technical integration of *Cyber-Physical-Systems (CPS)* in production and logistics as well as the application of the *Internet of Things* and *Services* in industrial processes. This also includes different means of adding value, new business models, service provision and work organisation.

Figure 2: Major Developments in Manufacturing Environments

Scalable CPS Architectures for Adaptive and Smart Manufacturing Systems

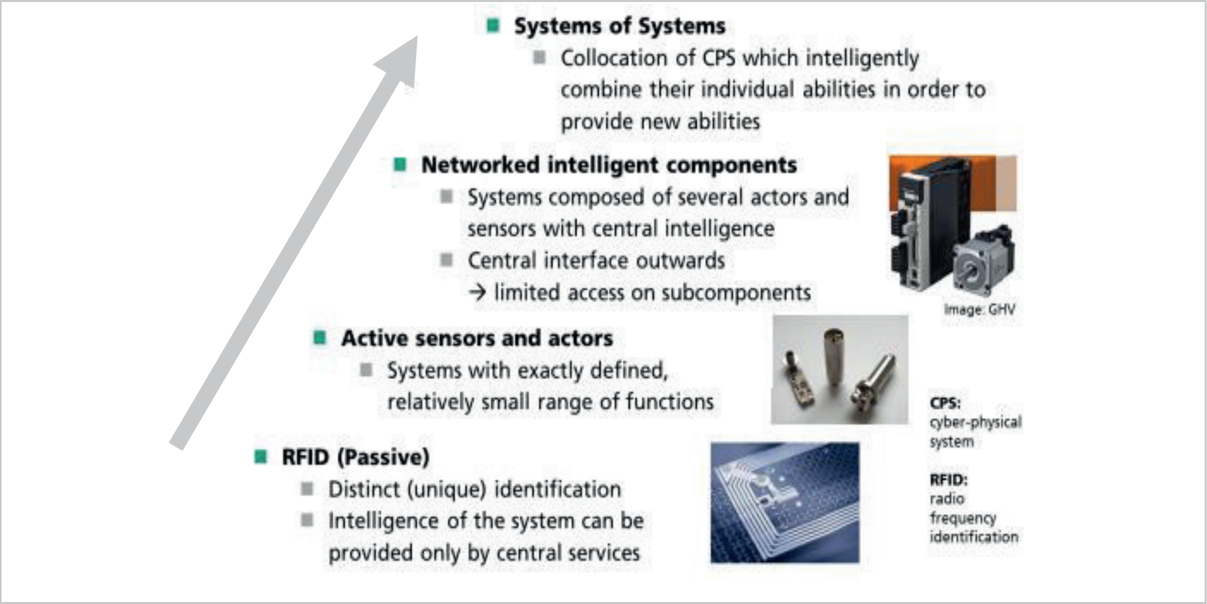


Figure 3: CPS Stages of Intelligence (© Fraunhofer IPA)

Exploitation of ICT tools and technologies offer increases in efficiency and quality throughout value chains, or the exploitation of additional markets, and manufacturing specifically addressing current market and customer demands. Smart manufacturing will exploit advances in wireless sensor technologies, M2M communication and ubiquitous computing, that would allow to track and trace each individual part of the production and monitor the individual phases. Together, an internet-style network of interconnected, intelligent machines are termed *Cyber Physical Systems* (CPS) (See Fig. 3) which according to the *industry 4.0 glossary of the VDI committee for industry 4.0*[1], is a system which interlinks real (physical) objects and processes with information processing (virtual / cyber) objects and processes by means of open and distributed networks. Additionally, a CPS can use local or remote available services, or provide man-machine-interaction. Especially when it comes to networked CPS, additional features like dynamic reconfiguration, continuous evolution, partial autonomy, and emerging behavior of CPS networks become important, too[2].

Figure 4: Modern Factory

CPS will provide a shared situational awareness to support network-centric production by closing the loop between the virtual world and the physical world. In order to exploit the full potential of CPS, various existing ICT systems have to be integrated, adapted to the industrial needs, and deployed on the shop floor.

[1] http://www.iosb.fraunhofer.de/servlet/is/48960/Begriffsdefinitinen%20des%20VDI%20GMA%20FA7%2021.pdf?comand=downloadContent&filename=Begriffsdefinitionen%20des%20VDI%20GMA%20FA7%2021.pdf

[2] http://www.cpsos.eu/wp-content/uploads/2014/09/CPSoS-flyer.pdf

Current Manufacturing Needs and Barriers for the Digitisation of Manufacturing Businesses

Due to globalised markets and increasing competitive pressure, manufacturing companies seek to optimise their business processes where possible. Frequently, this requires innovation with respect to manufacturing IT. However, other drivers for change exist, such as ever stricter requirements imposed by large buyers, new standards and regulations. Hence, there is a growing need for, *affordable* IT solutions. .

However, the vast potential of IT innovation in manufacturing still seems not to be recognised by manufacturing companies. IT is often perceived as a tool to accomplish a given task, but its potential to enable entirely new capabilities may be underestimated. One reason is that IT innovation tends to originate outside the field of manufacturing IT. An example of this is Ethernet technology from the consumer market that is now used pervasively in manufacturing. In the search for future manufacturing IT innovation, consumer IT markets are worth paying attention to providing a *"sandbox function"* for future manufacturing IT.

Over the last decades, many companies have implemented point-solutions, to add a specific feature or fix a specific issue. As a result the IT manufacturing landscape is highly heterogeneous often likened to a "wild garden". These IT landscapes are costly to administer and addition of further capabilities to the existing infrastructure is difficult and expensive. As a consequence many manufacturing companies do not exploit the latest manufacturing IT technology. Without a concerted effort to overcome this situation, or lessen the impact of it, manufacturing IT innovation will always be a slow process. It is not the *availability* of technology that poses a bottle-neck for IT innovation in manufacturing companies, but the fact that the latest manufacturing IT technologies are in effect out of reach for most manufacturing companies, especially SMEs, due to very high implementation costs. Introduction of IT also raises security and privacy concerns and today this is the number one show-stopper for manufacturing IT innovation.

Implications and requirements for future manufacturing IT solutions and architectures

To make manufacturing IT *affordable* solutions are needed that provide low setup cost, and easy integration with the existing IT landscape. New solutions must not interfere with already running processes, so seamless (and low risk) integration is required. Here, new models of renting software and cloud based approaches are presenting interesting pay for use models.

A flexible IT architecture is required which allows integration with and alongside existing systems (in an already operating factory in the majority of cases). The complexity of the system needs to be hidden from the owner as they are just interested in the information or service being provided. For cost effectiveness the infrastructure used to provide the service, e.g. cloud, may not actually be on site or owned by the factory.

Most important challenges and needs

Flexible manufacturing: Arguably the most important need for manufacturing businesses is flexibility. Many manufacturing companies describe flexibility as the need which has most strongly increased in importance over the past decade. The need for flexibility is driven by the trend towards shorter product life-cycles which, in turn, is caused by increased competition due to global markets. Another important driver for flexibility is the increasing demand for customised products as well as to anticipate and forecast demand changes and adapt internal operations accordingly. Unfortunately, with manufacturing IT landscapes as they are today (see discussion of the “wild garden” above), flexibility is precisely what is very hard to achieve.

Supply-chain flexibility: Since parts of the value-chain lie outside of plant or company boundaries, to attain the highest levels of flexibility at the plant level, the upstream supply chain must be flexible as well. Here it is also important to manage risk. The nuclear incident in Japan has shown, e.g. in the automotive sector, how vulnerable supply chains can be.

Cost reductions by improvements in business processes and in particular production processes: Global competition especially from lower wage economies has increased the cost pressure for many European manufacturers. In order to remain competitive many companies are actively looking to improve their operations by reducing start-up times and scale-up their production. They are also actively looking to reduce the effort needed for integration of new equipment and tools and reduce the start-up and maintenance times to improve overall production efficiency by manufacturing assets by using them more effectively.

Monitoring and Decision Making for Performance Optimisation: More efficient production requires more detailed knowledge about the production process. Today, in many industries measurements are taken at numerous locations. However, this tends to be acquired by a multitude of separate systems which are often not joined, correlated or shared. Manufacturing companies often have lots of data available acquired at the shop floor but struggle to derive information from it, i.e. to correlate it properly and derive decisions from it. This becomes even more difficult when decisions are required in real-time.

Integration of human worker in manufacturing process: Driven by the proliferation of mobile devices in the consumer sector, manufacturing companies increasingly want to apply mobile devices in a manufacturing context. A production manager who will be able to see manufacturing data in real-time on their smartphone or tablet is one example. It is likely that mobile devices will become a new form of human machine interface, enabling the worker to operate not just a single machine but interact with the entire production equipment, to obtain context information and correlated information from multiple sources, receive maintenance instructions, interact with big-data-based decision support tools and adjust processes based on real-time information. This will move decision making from a central control room to information being sent directly to the right person who can then take appropriate action. In the future, mobile devices will allow human beings to interact easily even with complex systems, and support informed decision making based on real-time information. Indeed, there is great synergy with developments stemming from the Internet of Things.

Road4FAME ICT in Manufacturing Roadmap

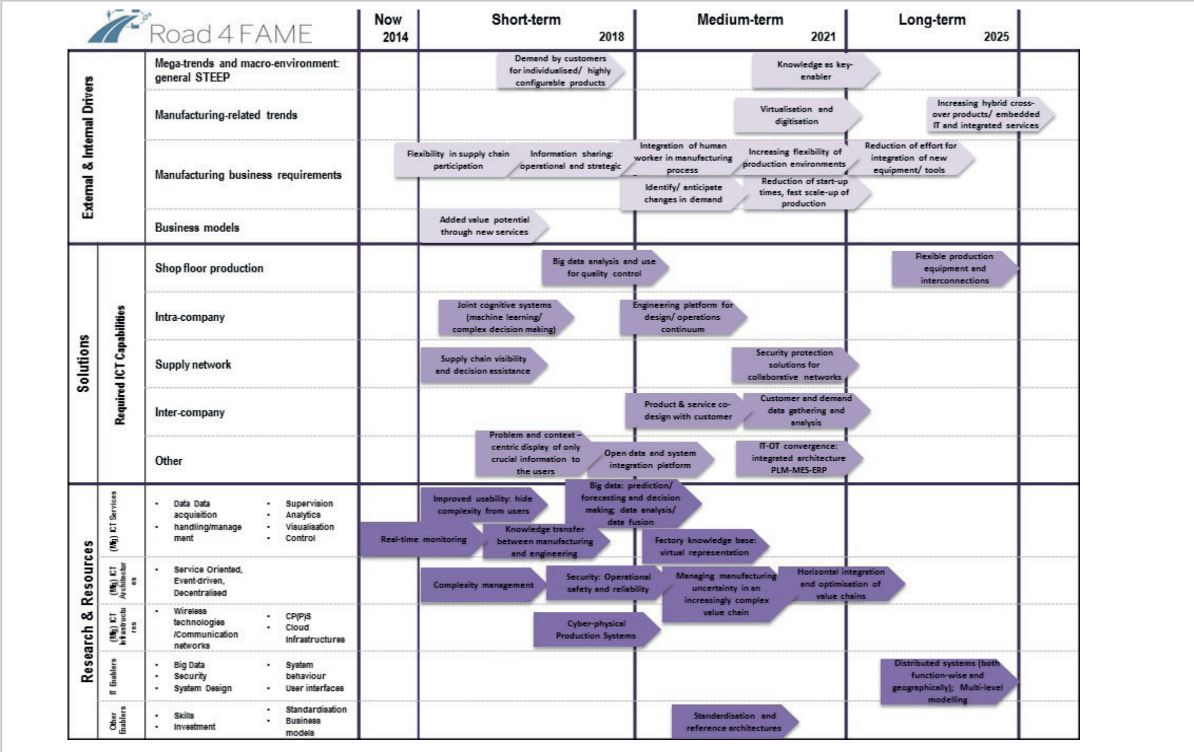


Figure 5: Road4FAME Roadmap

The Raod4FAME roadmap is shown in Figure 5 and spans from present time (2014-2015) to the short (2018), medium (2021) and long term (2024). It consists of three layers: External and Internal Drivers, Solutions and Research and Resources. Each layer consists of several sub-layers as follows:

External and Internal Drivers

This layer provides external and internal drivers and trends – 'why' things are done including:

- **Mega-Trends & Macro-environment** includes generic 'STEEP' factors – those macro-environmental sociological, technological, environmental, economic and political factors which are generally applicable.
- **Manufacturing-related trends** – relates more directly to manufacturing industry itself, and looks at trends within the industry.
- **Manufacturing business requirements** – this defines how manufacturing trends and drivers in the layer above translate into needs to manufacturing businesses.
- **Business models** – the routes by which value is delivered by manufacturing businesses.

Solutions

The Solutions layer considers 'what' needs to be provided to address the needs, trends and drivers in the 'why' section above from the perspective of manufacturing industry. This includes the required ICT capabilities - the functionality required to support the stated manufacturing business requirements now and in the future including:

- **Shop floor production** – These are ICT Solutions predominantly affecting operations within the production area.
- **Intra-company** – These are ICT Solutions necessary for the smooth operation of a company as a whole that link different departments or functions together. They

may include coordination and business processes for production, finance, sales, dispatch, etc.

- **Supply network** – These are ICT Solutions required for a business to coordinate its activities with its own supply network.
- **Inter-company** – These are ICT Solutions enabling business operations with available suppliers, partners, customers etc.
- **Other**

Research and Resources

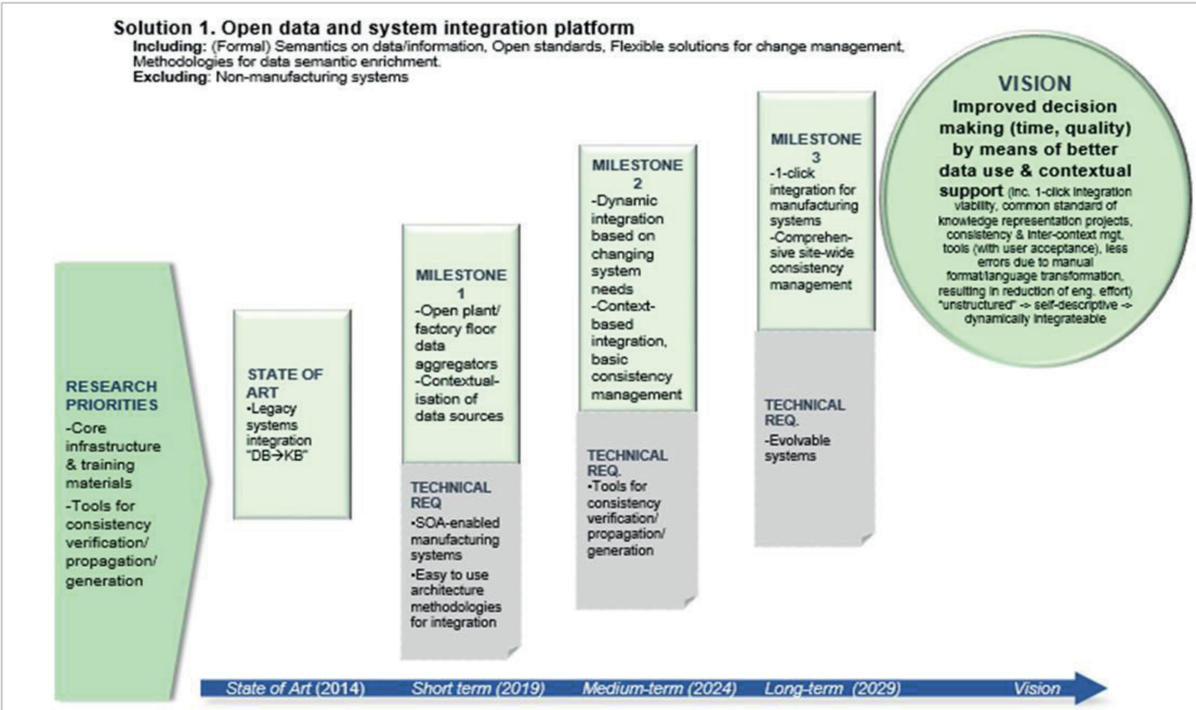
This section considers 'how' the 'what' can be achieved to address the 'why'.

- **(Manufacturing) ICT Services** - these provide encapsulated functionality – e.g. a browser enables browsing of the internet by means of defined interfaces.
- **(Manufacturing) ICT Architectures** – these describe the means of organisation – i.e. it is a framework of how to integrate and connect services together to create the overall functionality. Often there is a hierarchical architecture in manufacturing e.g. sensors and actors, EPLC level, manufacturing execution system, and then enterprise resource planning (ERP) system.
- **(Manufacturing) ICT Infrastructures** – these are hardware or IT related, which enables use of hardware in some way. It is the underlying 'thing' on which architectures and services are realised, e.g. cloud computing.
- **IT Enablers** – non-ICT technologies that enable ICT developments.
- **Other enablers** – skills, investment (funding required for the developments identified, together with potential sources), standardisation and business models.

Content was collected initially through desk research, literature review and consultation of other related roadmaps in the domain. The content was enhanced through face-to-face interviews predominantly with manufacturers and was reviewed, enhanced further and prioritised through three roadmapping workshops with participation from European manufacturers, ICT providers and academics. The full list of contributors to this roadmap, European coverage and contributor background is shown in Appendix A.

The 11 key solutions identified are described in more detail in the following sections giving the vision, and roadmap to achieve that vision, along with case study examples as well as barriers and enablers to implementation. Finally, recommendations are also formulated.

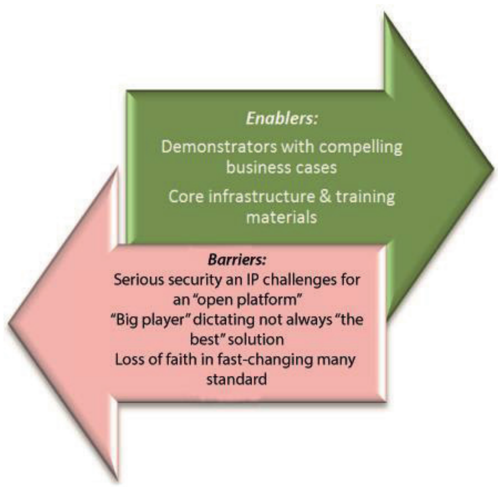
Open data and system integration platform for an unstructured data environment that includes harmonised / standardised interfaces



Manufacturing systems contain a multitude of equipment, processes and software solutions. The reduction of integration and set-up costs for new tools and equipment, especially when these are incorporating novel ICT components and systems, is a major issue.

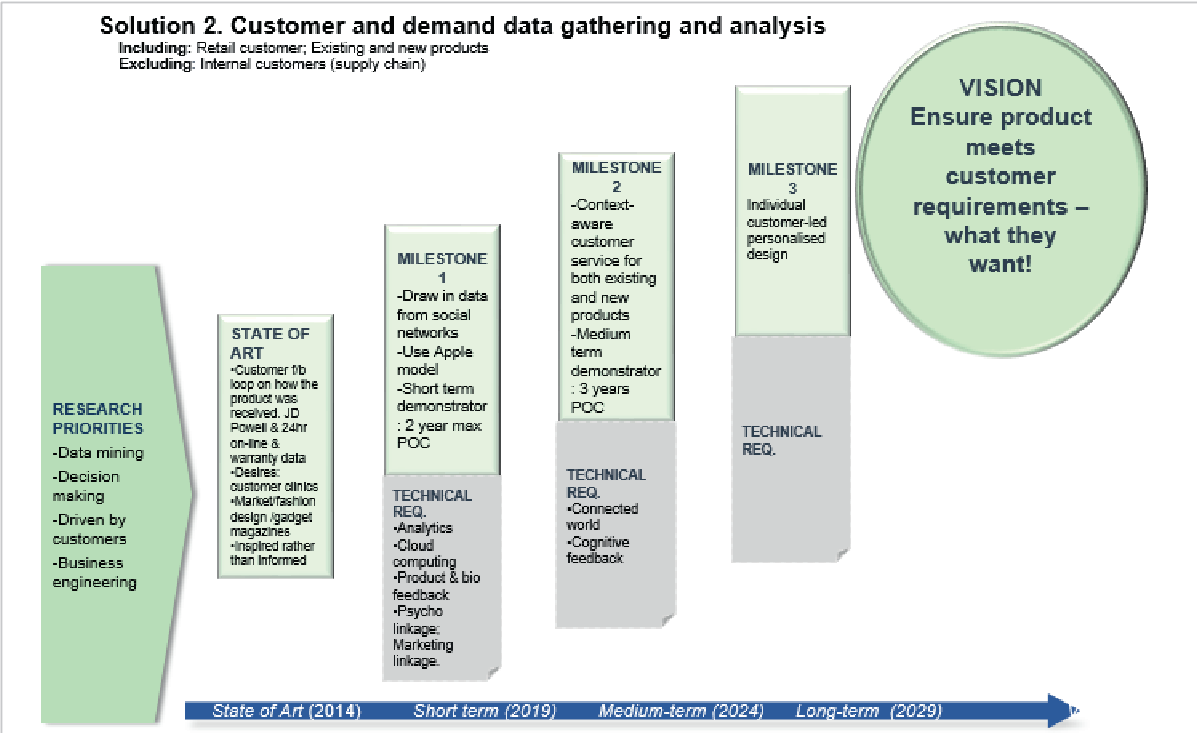
Case study: *A lab equipment manufacturer is producing a large range of medical diagnostic products for research. In recent years it has been investing heavily in new software to try to obtain seamless information flow from order receipt to dispatch within the business. It has found that its productivity has not increased as expected and that it still takes a large amount of time to manually collect, integrate and update the information from component design, production schedule, stock control and ordering systems as all these run on different software packages.*

A possible solution to this is the development of an integration platform that facilitates the collection of "raw" (i.e. unstructured) data from different sources and integrates it into predefined (contextualised) fields to facilitate review and decision making. This solution would enable the progression from dealing with "unstructured" data to self-descriptive and eventually dynamically integrable data sets. This requires semantics for data/information, methodologies for data semantic enrichment, open standards and flexible solutions for change management. Such a platform should provide an "one-click integration" for manufacturing systems with comprehensive site-wide consistency. This would facilitate the faster development of complex, customisable products.



The ***implementation challenges*** are to develop a core infrastructure and supporting training materials for such a platform and invest in research around data quality, tools and methodologies for generating, distributing and verifying consistent datasets within a manufacturing environment.

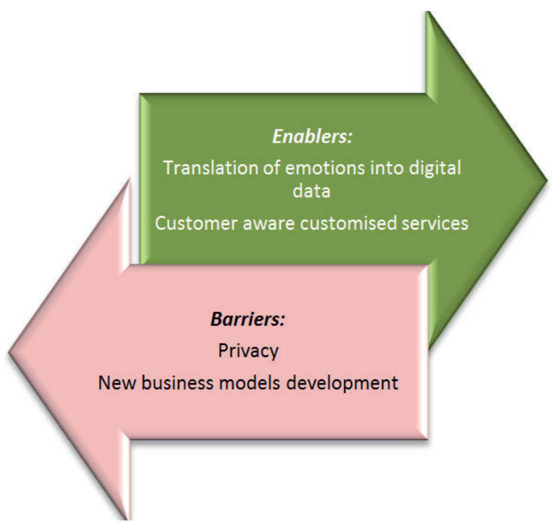
Customer and demand data gathering and analysis



There is an increasing demand especially in developed economies for customisable products that are both designed to a customer's specifications and produced and delivered fast without compromising product quality and performance. This poses a significant challenge to manufacturers who need to design and produce a new product or reconfigure an existing one such that it always meets customer requirements and provides them with exactly what they want. This becomes more difficult for mass produced retail products.

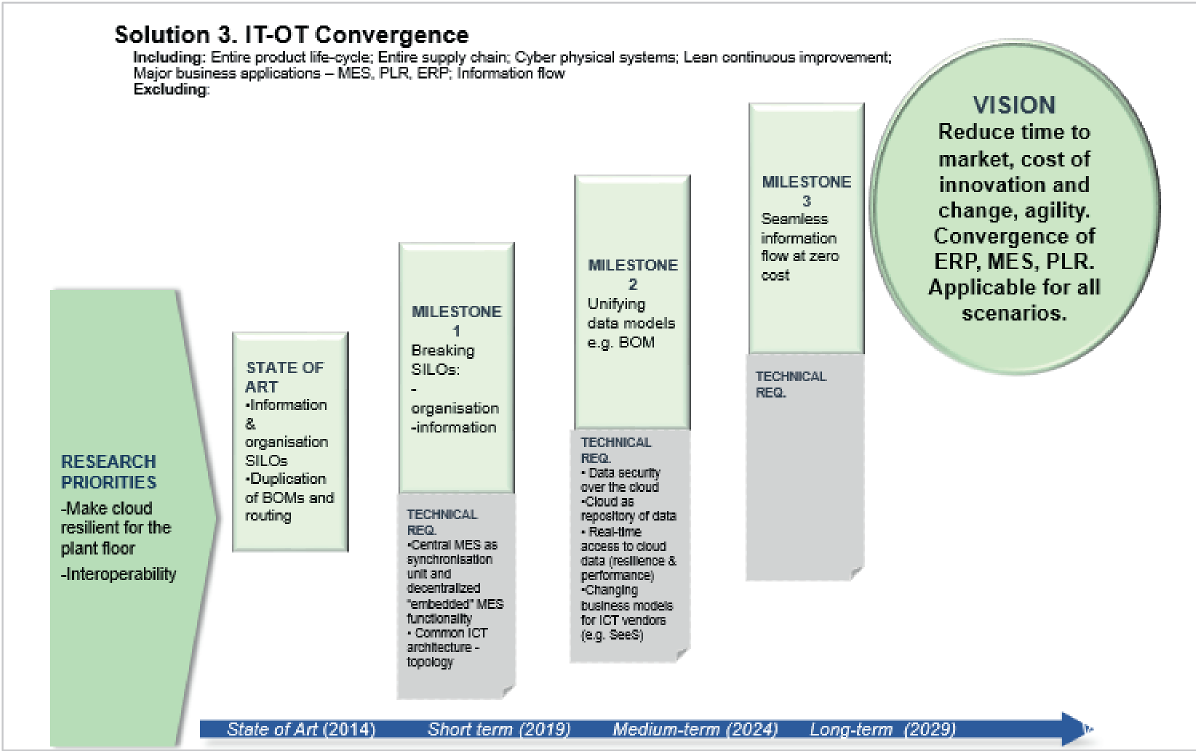
Case study: *A large car manufacturer is keen to offer to its high end customers the option of custom-designed cars (size, colour, engine, etc.). For this initiative to be successful, the manufacturer needs first to understand which product characteristics the customers would like to customise initially and why. Given the disperse geographical location of its customers and the different usage patterns they follow, the manufacturer is considering the implementation of intelligent embedded components into its existing cars that can feed back real time customer usage information.*

An important first step to realisation of such a system would be the collection of customer data that includes feedback on existing product use, future desires and preferred designs. Initially this can be achieved through standard feedback methods, but in future data from social networks could be used and eventually a fully context-aware data collection system could be developed, implemented and used within companies.



The ***implementation challenges*** are for research on data mining and decision making. It is also important to research aspects of business engineering and business model development to facilitate the implementation of such solutions.

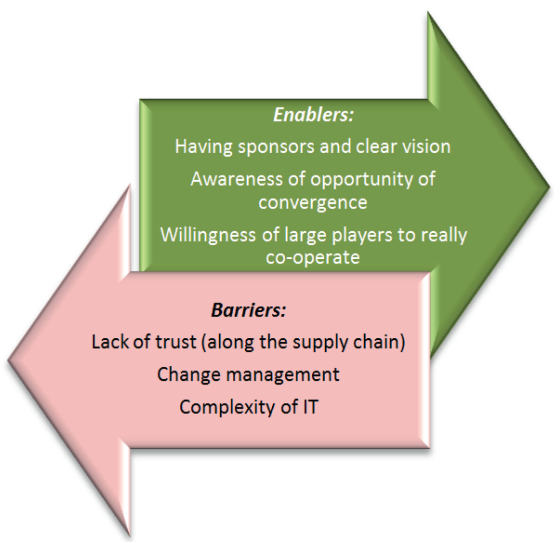
Information technology and operational technology convergence



It is not uncommon for manufacturing companies to use several different software systems especially between the production shop floor and other company divisions such as product design or customer support. Examples of this are tools for Product Lifecycle Management (PLM), Manufacturing Execution Systems (MES) and Enterprise Resource Management (ERP). This creates unnecessary barriers in the information flow within a company and adds delays in the introduction of new products and the reaction time of an organisation to market demands. This potentially increases the costs of innovation and weakens the market position of the business.

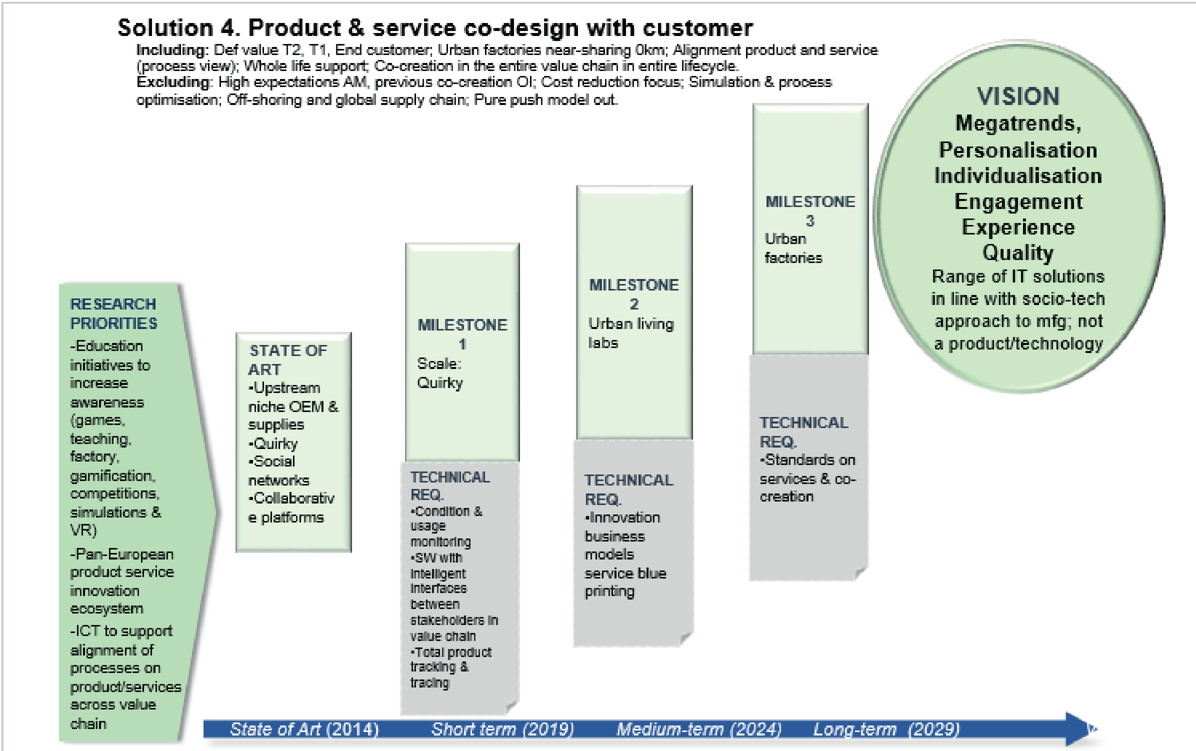
Case study: *A precision engineering company is producing a large number of components a day for the aerospace industry. In recent years it has been investing heavily on new software to new 5-axis equipment and robotic handling systems to increase its manufacturing capacity while keeping production overheads low. Unfortunately, the company has found that in order to remain responsive to its customers it had to employ new staff to just enter, extract and analyse the data between the different software packages they run internally (CRM, ERP and CAD etc.).*

Ideally, most companies would like to have a fully interoperable business system with convergence of current major business ICT applications such as ERP, MES and PLR. The convergence should be applicable throughout a product's life cycle and involve the entire supply chain. Such a system will enable seamless information flow from a variety of cyber physical systems and break current information and business silos.



The ***implementation challenges*** are for technology development around cloud computing resilience for the plant floor and on interoperability development.

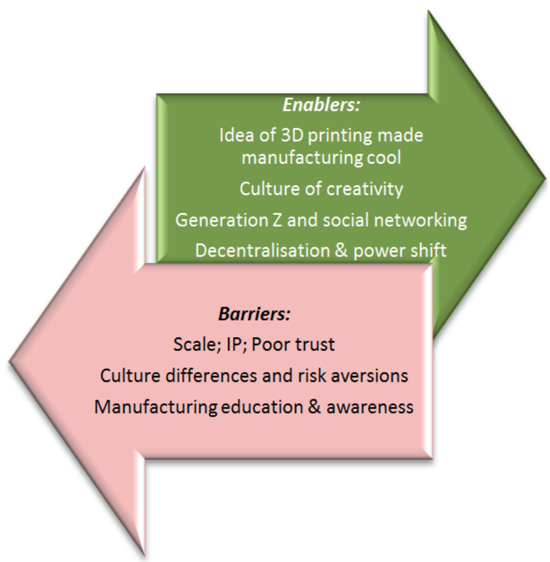
Product and service co-design with customer



Current socio-technological trends in manufacturing foresee an increasing demand for product or service personalisation, individualisation, active customer engagement and product or service co-creation. Manufacturers are looking for ways of addressing this trend while maintaining control of their costs. The co-creation involves the entire value chain throughout a product's or service's lifecycle and requires an alignment of a product and service during this period. It may ultimately require the creation of urban factories in close proximity to customers that manufacture quickly and on-demand fully customisable products.

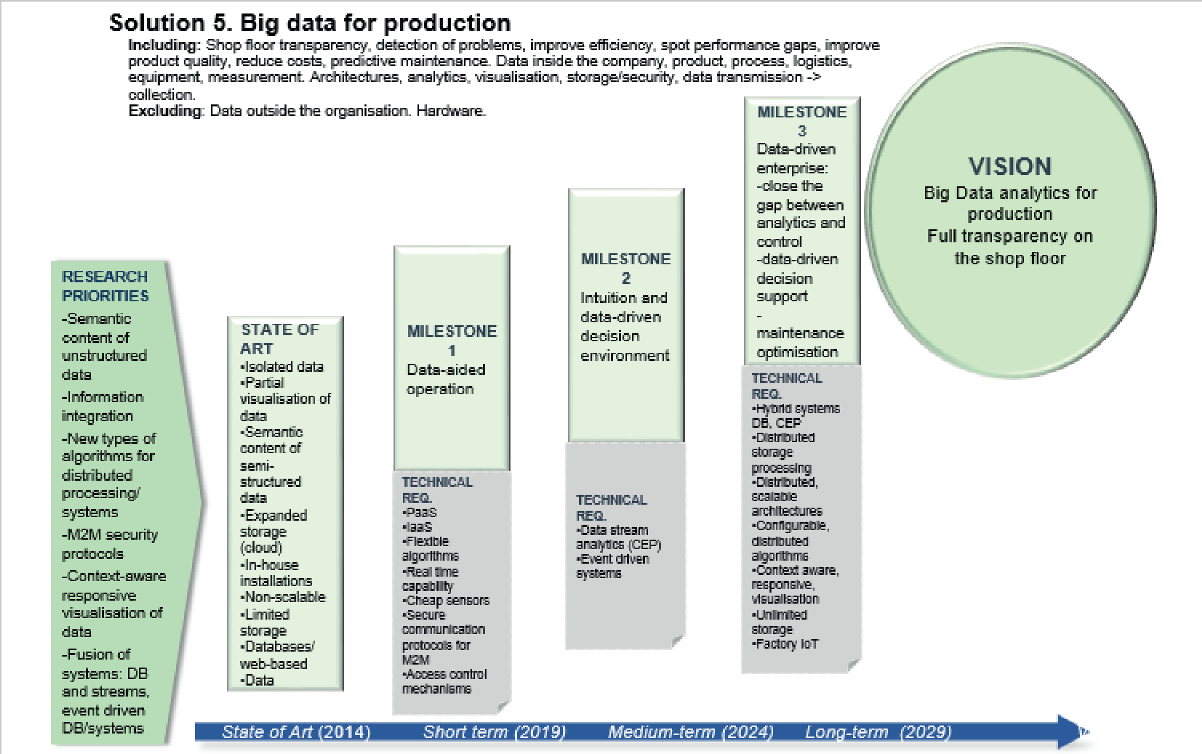
Case study: *A young, dynamic company offers custom-designed nutritional supplements to professional and amateur athletes. The products need to be designed weekly for each athlete depending on their individualised training regime. The company has a number of highly valuable customer contracts that it is keen to develop into profitable long term relationships. In order to do so it understands that it must work closely with each of its customers to respond effectively to their unique and changing requirements. At the same time, it has to scale up its operations, optimise the number of employees, infrastructure, working hours and customer support systems to provide its clients with the products they require while remaining profitable.*

An innovative ICT solution is required to support such a shift in current manufacturing practices. Ultimately, the product/service value will need to be defined for each partner in the supply chain to make the ICT solution viable and implementable.



The ***implementation challenges*** are for the development of ICT systems to support alignment of processes on product/services across the value chain supported by a range of modelling and simulation systems and a Pan-European product/service innovation ecosystem. There is also a need for education initiatives to increase awareness.

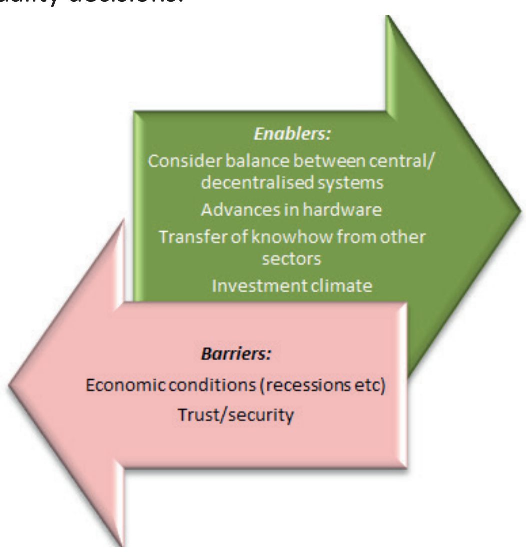
Big data analysis and use for quality control



In the last 50 years quality control has become one of the cornerstones of manufacturing. Most methodologies used focus on early detection of faults and defect prevention. The gradual integration of embedded, intelligent components into both production systems and products has raised the possibility of developing real-time big data analytics for production. This has the benefit of enabling full transparency on the shop floor and helping improve product quality, by spotting performance gaps and detecting problems early thus improving the overall production efficiency and reducing costs.

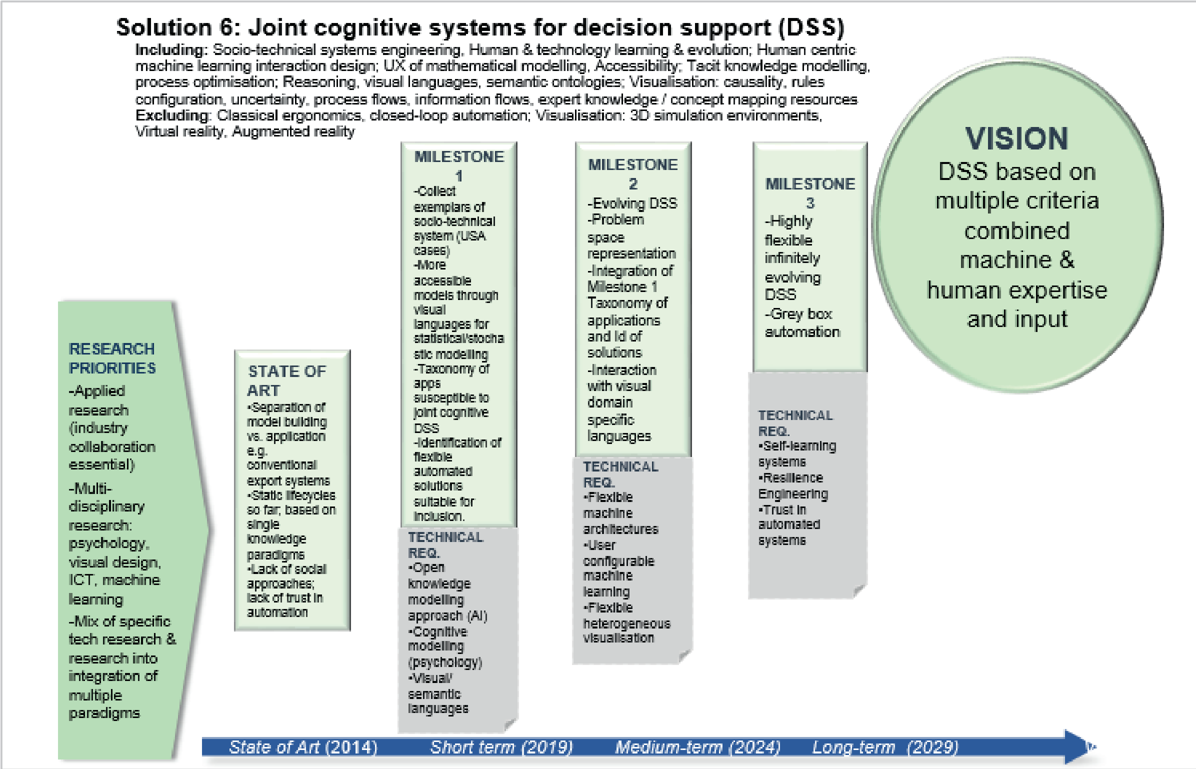
Case study: *An Infra-red equipment manufacturer produces specialised electronic instrumentation for fire brigades around the world. Although the manufacturer has copious quality control processes in its production and an exhaustive testing regime of the instruments before dispatch quality issues still exist. The company would benefit from a system that provides early quality alerts to its production staff of faulty or misaligned components.*

For this to be achieved new architectures, analytics and visualisation as well as data transmission, collection, storage and security systems need to be developed, trialled and implemented. Visualising the data in a meaningful manner to help shop floor staff make informed decisions can be laborious. In the future, production environments can be transformed into data-driven decision environments where data from many operations within an organisation such as product design and production, process, information, real-time data mining, event and equipment monitoring can be collected and used to aid quality decisions.



The ***implementation challenges*** are for adding semantic content to unstructured data of systems and new ICT architectures (hybrid systems).

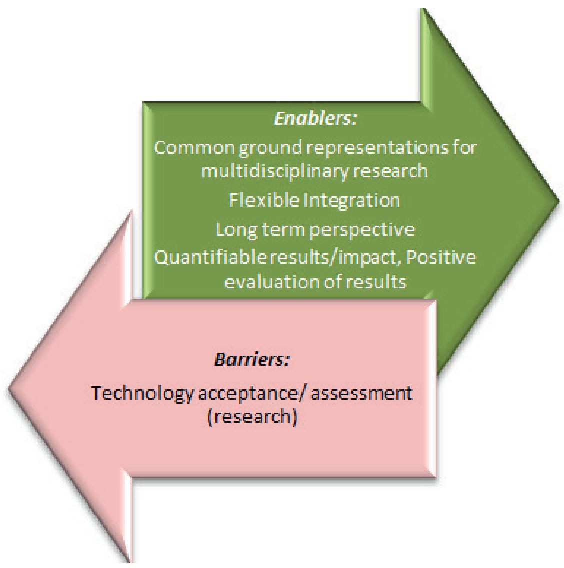
Joint Cognitive Systems for decision support (DSS)



An intra-company Decision Support System (DSS) combines machine and human expertise to facilitate decision making. It is a human-centric, machine learning system that enables learning and evolution with time and is able to model human tacit knowledge to improve various business processes.

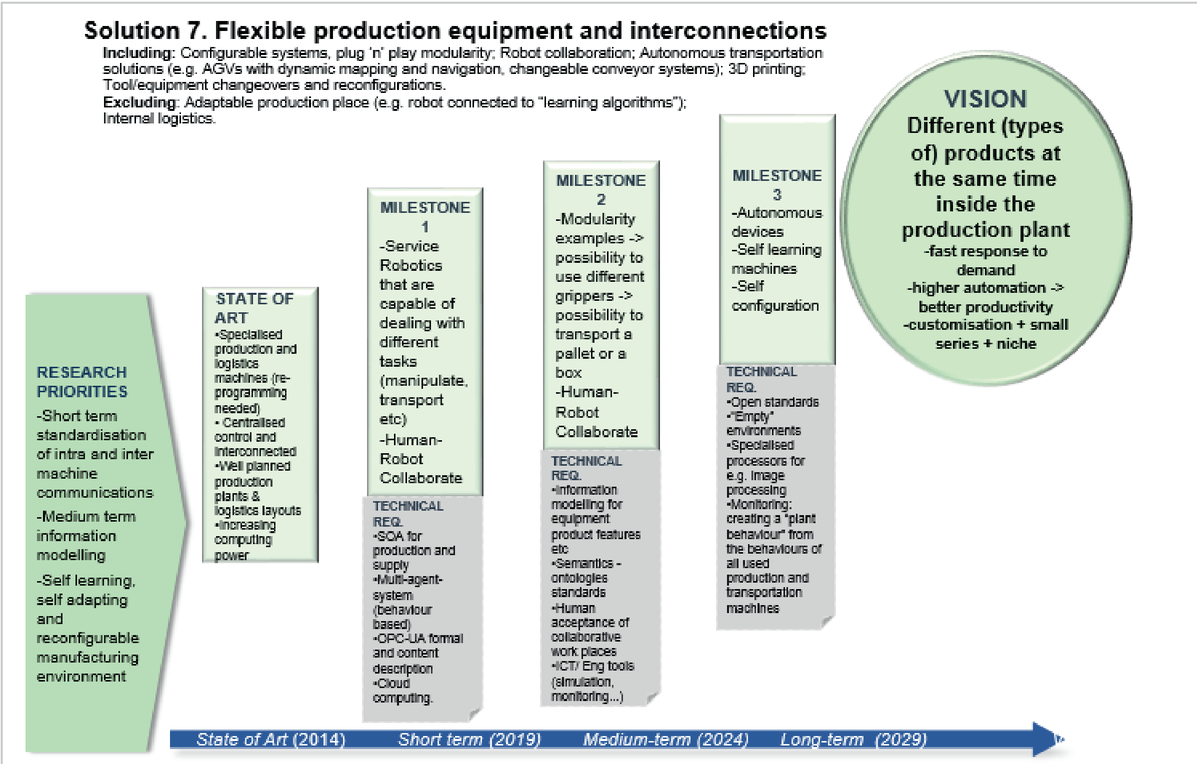
Case study: *A large multinational company of temporary housing for emergency situations has several manufacturing sites around the world. These produce the same products, which there are distributed locally according to specific emergency situations. Over the years due to cultural differences and changes to the availability of local technical expertise variations in the production processes for the same product have become evident. This coupled with large variations in demand for the same product from different regions have resulted to some factories to be less efficient. The company would like to have an "intelligent" system to map existing processes, understand and share the tacit knowledge that is important and optimise the manufacturing processes to local demand.*

The aspiration is to develop a DSS that is highly flexible and infinitely evolving with the needs of the business. This will integrate human centric machine learning interaction design, Use eXperience (UX), tacit knowledge modelling, process optimisation reasoning, formal specification of a shared conceptualisation (i.e. semantic ontologies) and visualisation languages. 3D simulation environments as well as virtual and augmented reallity, will be critical for assessing process and information flow, mapping of concepts, and resources and expert knowledge.



The ***implementation challenges*** are for applied research in range of subjects such as, psychology, visual design, machine learning and modelling of socio-technological systems including visual encoding and artificial intelligence algorithm development.

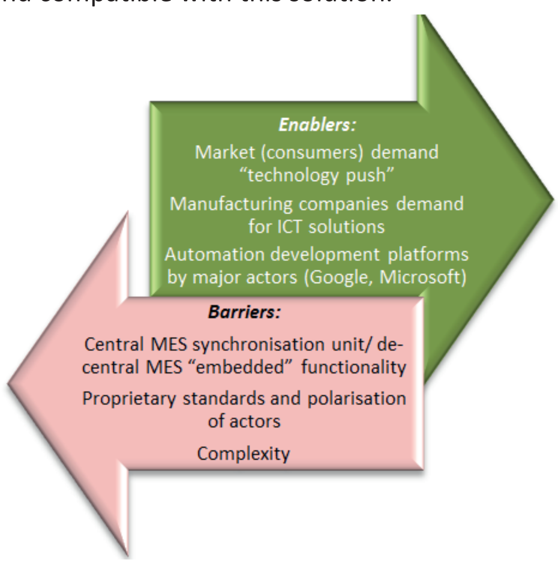
Flexible production equipment and interconnections



In many manufacturing environments a single production line is used for a range of different products. This often creates issues for change-over time, tolerances and quality control. It can also constrain new product development if new or different production processes are required. Many manufacturing businesses will welcome a solution that enables different types of products to be manufactured using the same production plant. Such a solution can significantly increase the response time of a business to market demand.

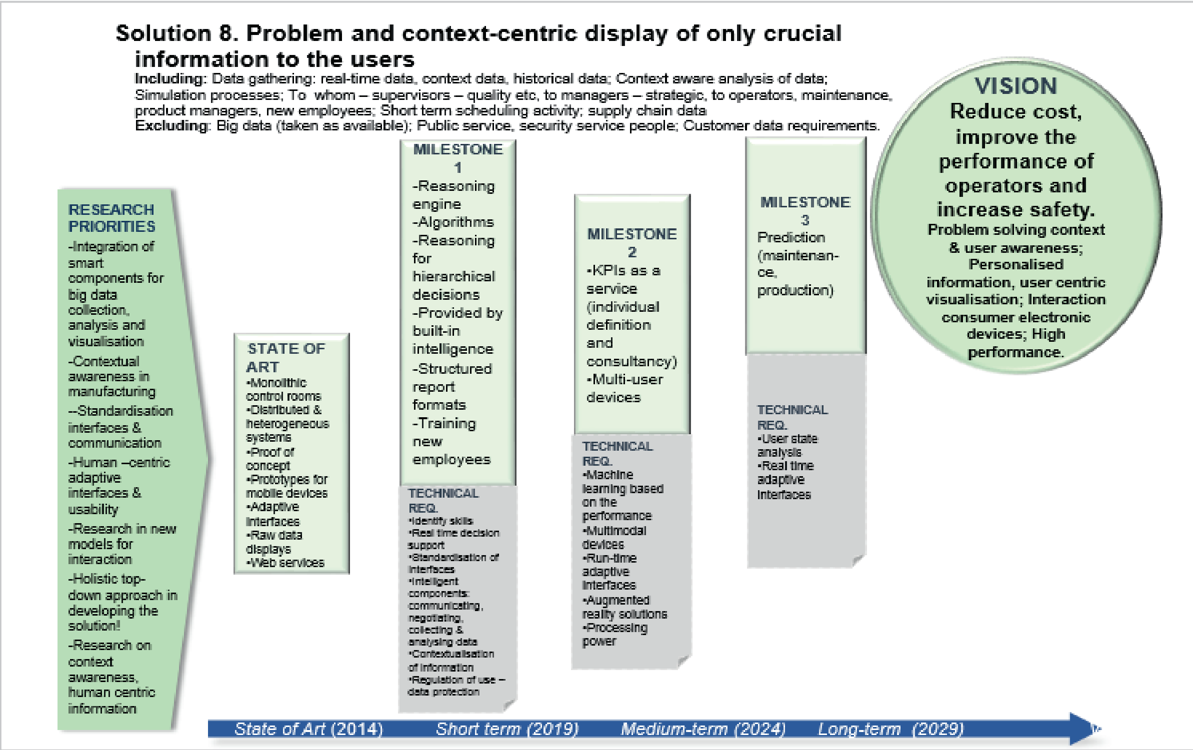
Case study: *A large manufacturer of baby food products manufactures over 100 different products each week using the same production facility. Due to the high variety and volume of the products made, any issues or small delays can significantly increase the overall annual production costs. The company would like to have a fully automated, "intelligent" production system that optimises the production flow for each product, allows for new products to be introduced, detects any quality issues in real-time and reduces the need for manual intervention.*

Typically, such a solution would require configurable systems that have plug-and-play modularity, tools and equipment that can be changed and reconfigured easily, robot collaboration and autonomous transportation solutions for example, automated guided vehicles (AGVs) with dynamic mapping and navigation or changeable conveyor systems. The latest production techniques such as 3D printing could also be useful and compatible with this solution.



The ***implementation challenges*** are for standardisation of intra- and inter-machine communication, information modelling and self-learning, self-adapting and reconfigurable manufacturing environment.

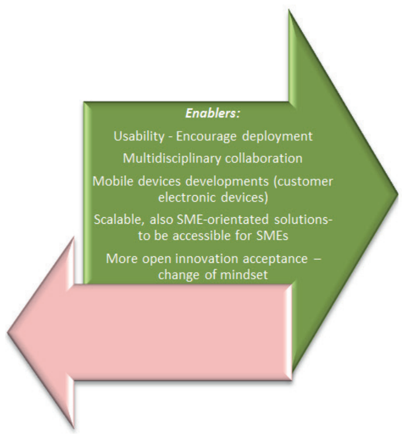
Problem and context-centric display of crucial information to users



Visual management systems already exist in many manufacturing environments. These normally enable faster communication and improve adhesion to key processes, especially in situations with strong cultural differences or language barriers. This particular solution aims to provide personalised information and user centric visualisation within an organisation to aid different employees (e.g. supervisors, operators, product managers, etc.) in problem solving. Current solutions tend to be "monolithic" i.e. centralised, fragmented and static. In the future "live" information can be provided in a personalised format to enable better and faster problem identification.

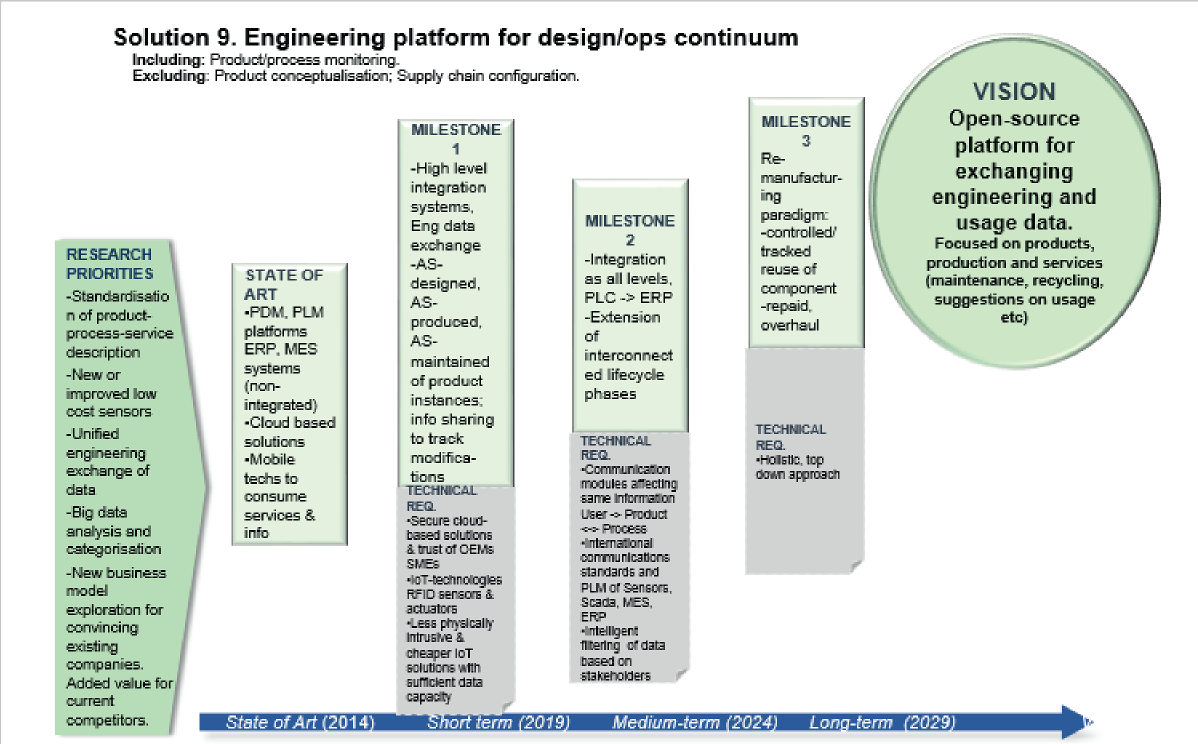
Case study: *A manufacturer of household cleaning products operates a continuous production line. Health and safety protocols are paramount in the production area as corrosive and flammable liquids are in frequent use. Although the company trains new employees, accidents still occur by people not understanding and/or not adhering to process instructions. This has led the company to recruit more production supervisors which has led to a sharp increase of operating costs.*

The solution assumes that different types of data (e.g. historical, real time, context, etc.) are available from different business areas (e.g. supply chain, scheduling, production, etc.). These data are used as a baseline for performing context-aware analysis of the information and simulation processes to assist decision-making. The implementation of the solution is enabled by the use of consumer electronic, multimodal devices throughout the business. The benefits from such a system can be multiple, reducing cost, increasing safety and improving the performance of the operators.



The ***implementation challenges*** are for the integration of smart components for Big data collection, analysis and visualisation, human-centric adaptive interfaces and research into new modalities for interaction, developing contextual awareness for different manufacturing environments, standardisation of interfaces and communication potentially including self-configuration.

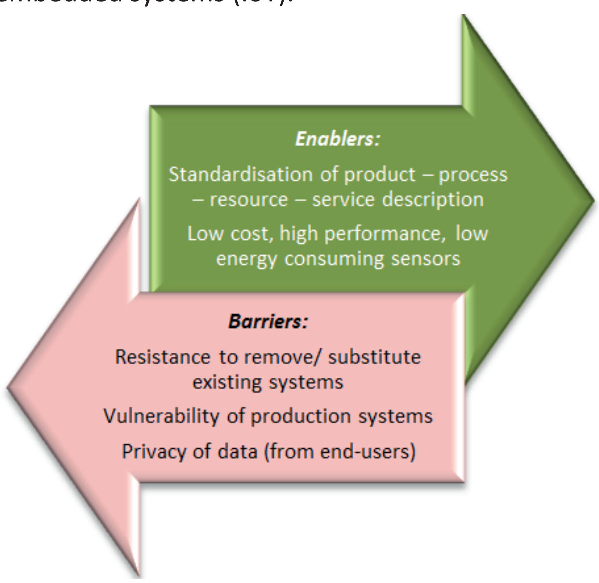
Engineering Platform for design/operations continuum



This ICT solution requires product and process monitoring and exchange of engineering and usage data throughout the whole product lifecycle. Using a common language, the ICT system helps to aggregate different views about the product, its use and the resources utilised. The information is presented in a virtualised product/production format that also allows enhanced meta-information to be captured. This can evolve during the product lifecycle and assist with future product reconfigurations improving communication between different lifecycle phases.

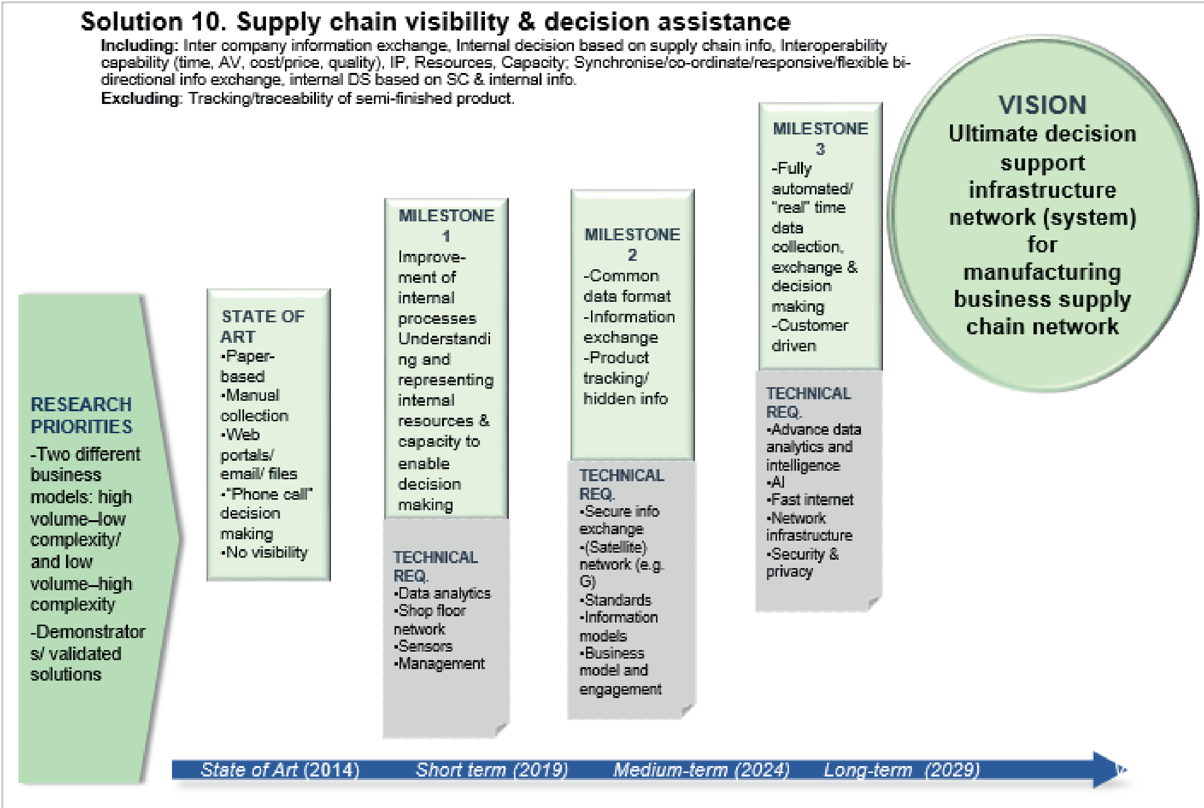
Case study: *A leading white appliances manufacturer would like to improve the environmental performance of its products and gain a competitive edge over other suppliers. It has started to incorporate small sensors into its goods and monitor how the products are used and the amount of energy they consume while operational.*

This solution is designed on an open-source platform for exchanging engineering and usage data. It is focused on products, production and services (maintenance, recycling, usage, etc.). It is an important enabler of concurrent engineering facilitating the development of low cost configurable solutions. For its implementation the availability of low cost sensors it is essential, as well as tracking systems (passive RFID, QR codes) or embedded systems (IoT).



The ***implementation challenges*** are for unified engineering exchange of data, standardisation of product – process – service description, Big data analysis and categorisation, Big data analytics for both production processes and product usage, secure cloud platform development and standards with universal acceptance and miniaturisation of smart, low cost sensors.

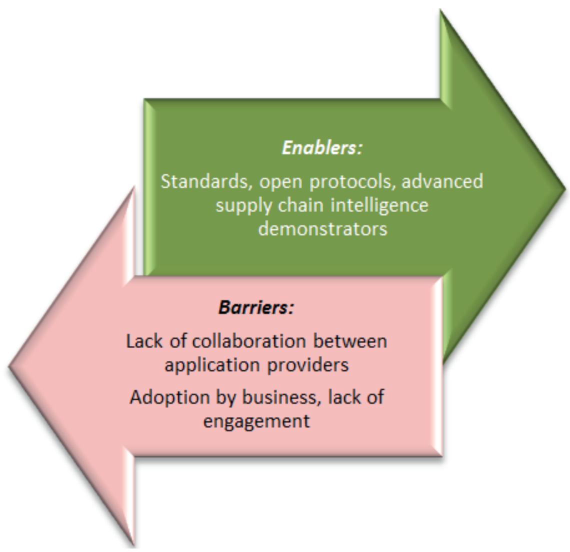
Supply chain visibility and decision assistance



This is a decision support system for manufacturing businesses' supply chain network. It helps companies synchronise, co-ordinate and communicate with their supply chain having a flexible, bi-directional information exchange system.

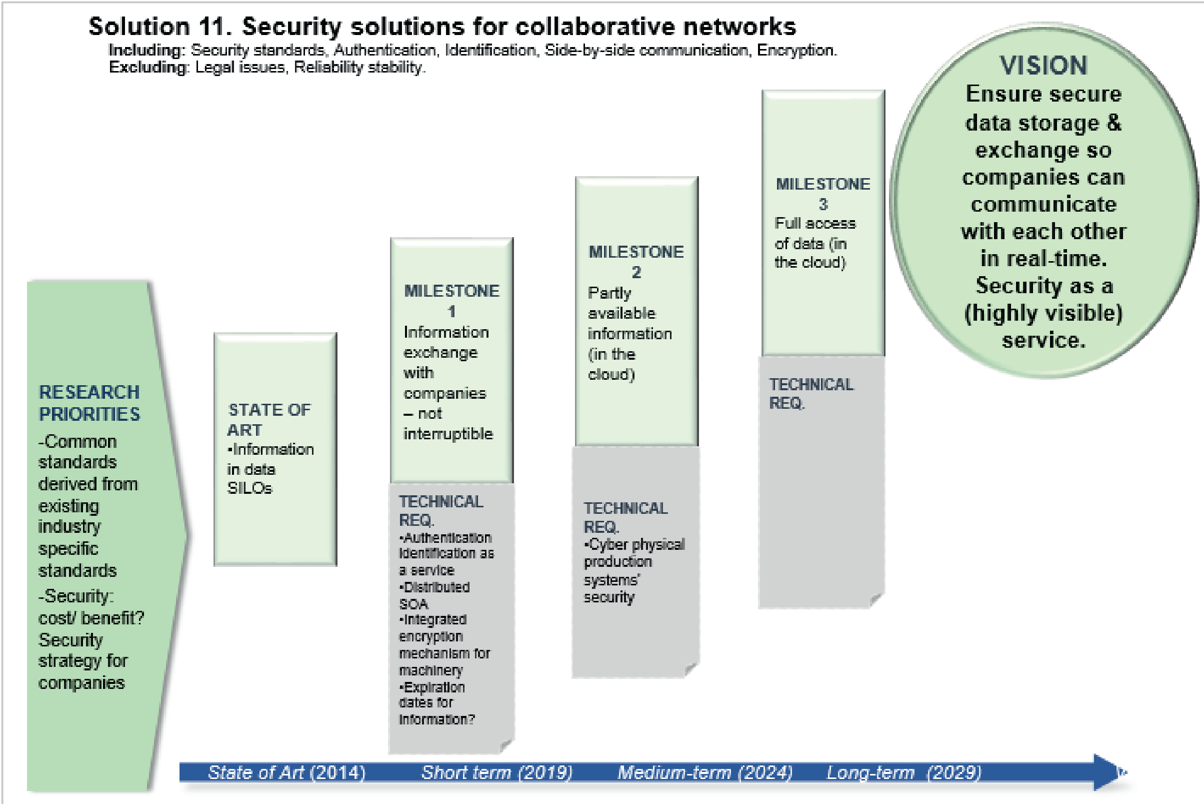
Case study: *A small manufacturer designs and sells specialised components to large OEMs in the automotive industry. The component design needs to take into account the design of many other components made by a range of other suppliers, in order to be integrated seamlessly into the final product. The manufacture and supply of all the components also needs to be co-ordinated between all the suppliers as the OEMs tend to penalise suppliers by delivering too early or too late.*

With this solution internal decisions can be based on information provided by different suppliers in their supply chain taking into account time, cost, quality, IP, available resources and capacity. Currently, many decisions rely on paper-based, manual collection of information assisted by web searches, email, files and phone calls. In the future a fully automated, real-time data collection and information exchange system could be implemented to facilitate decision making.



The ***implementation challenges*** are for research on data analytics, information models, development of pilot demonstrators to validate possible solutions, and standards development.

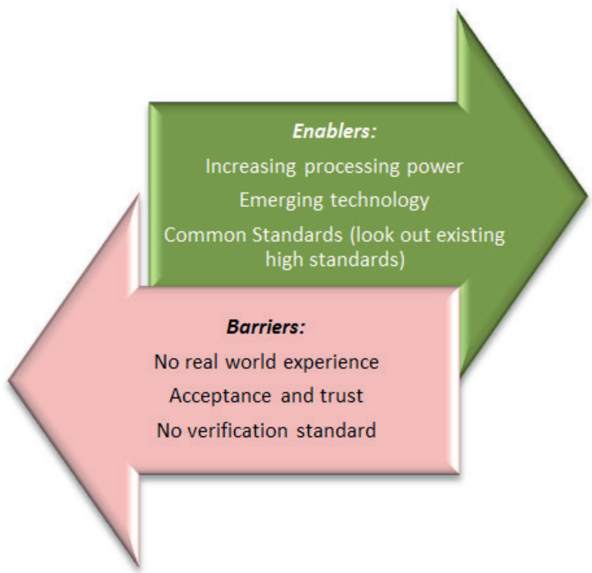
Security solutions for collaborative networks



This ICT solution enables secure data storage and exchange between different companies in real-time. It provides services for authentication, identification and encryption in secure platforms using robust security standards.

Case study: A high-tech start-up company is trying to establish an eco-system of collaborators and partners to speed up the adoption of its cutting edge technology by the market. The start-up runs a several research projects with its partners and has different scientists leading different projects. Recently it realised that some activities are duplicated internally and within the partner organisations and it would have been quicker and more cost effective to share certain data internally and with its partners.

Currently, information and data tend to be compartmentalised and stored within individual organisations often in "data silos". Information exchange with other companies is not interruptible. In the future, relevant information will become available in the cloud with full access to all partners in a specific network.



The ***implementation challenges*** are for investigation of all common standards derived from existing industry specific standards, developing credible security strategies for companies and developing security options with clear cost-benefit ratios.

Research Recommendations

The following recommendations were highlighted as the most important.

Reference Architectures / Open Architectures
Many projects have generated reference architectures. These could be transformed into open architectures, which can either be implemented, further developed or adapted by other projects to improve them further.

System/Information Integration Architectures
System and Information Integration Architectures are becoming increasingly important due to the growing heterogeneity, amount of information and system components available and they need to be addressed to cope with this challenge.

Data Capture, Storage and Analysis
Technology to capture, store and analyse data is advancing from a technical standpoint, but specifically from a methodical and legal side further developments are needed to enable efficient sensor data and information handling, enabling business models and innovation, while protecting individuals and companies.

Data and Information Visualisation
Visualisation techniques and specifically context-aware responsive visualisation of data is a major pre-condition for efficient decision support systems. Human-centric adaptive interfaces and context-centric displays are needed to only present crucial information to enhance usability.

Security
Research into security strategies for companies and standards to protect the networked supply chain would be necessary to ensure balance between security cost and benefits to an organisation.

Confidentiality
Confidentiality and know-how protection throughout the supply chain of the increasingly higher interconnected networks is essential for the acceptance and application of new ICT architectures and services in manufacturing. Therefore evolution of authorization, authentication and encryption mechanisms to cope with this scenario is recommended.

Flexible and Adaptable Manufacturing
New ICT Infrastructures should be researched that promote self-adapting, resilient and reconfigurable manufacturing environments. These need to be facilitated by standardiaation of intra- and inter-machine communication, but also need to reflect production process aspects. New networking protocols and mechanisms will have to improve the linking of various equipment such as actuators, and (wireless) sensors, RFID devices, etc., significantly contributing to efficiency improvements of the (re-) configuration and ramp-up of manufacturing environments. Additionally, appropriate context awareness, human-interaction and self-learning (e.g. for production configuration) mechanisms have to be developed based on continuous realtime monitoring of logistics, material flow and resource utilisation.

New Algorithms
The development of ready to use algorithms for analysis, real time prediction, etc., will need to meet the needs of every manufacturing enterprise, without organisations, especially SMEs, having to spend additional time and resources on the definition and development of those algorithms. Furthermore, those algorithms should be able to run on limited processing / power capacity to ensure their applicability in manufacturing environments. Here cloud connections may allow access to external computing. New algorithms can also

incorporate knowledge from other domains that could be beneficial to manufacturing (e.g. game theory, artificial intelligence, simulations, etc.).

Modelling
Modelling, and in particular, information and work domain modelling of socio-technological systems would be beneficial in manufacturing. Simulations, virtual reality, tacit knowledge modelling and UX of mathematical modelling can be important for enabling better problem solving and decision support and rapid prototyping. The development of smarter and better models can provide not only design detail but also greater predictive capacity in order to reduce physical prototyping needs or construction of pilot plants.

New or Improved low-cost, miniaturised smart sensors
Sensors need to become cheaper, smarter, smaller and more energy efficient, to enable new applications which until now were not viable due to technological constraints.

CPPS – Cyber-physical Production Systems
CP(P)S concepts need to be further evaluated and implemented. Specifically self-description, integration/interface and intercommunication standards need to be developed for platform and system integration.

Interoperability and Standards
Existing standards need to be examined and adopted if possible. Contributions to improve existing standards are also encouraged. Standards for interoperability will become even more important for the envisaged platforms, products and services of the future.

Establishing of Demonstrators
Demonstrators need to be promoted and supported in order to show the feasibility and chances of new technologies and new solutions. This is a way to demonstrate the technological and economic opportunities especially for SMEs.

Incorporation of psychology into ICT research
Incorporation of Psychology into ICT research is fundamental in order to develop joint cognitive decision support systems. These systems are able to take decisions by themselves; for this purpose, human-machine collaboration is essential. This is only possible by combining psychology with ICT research in order to get a more effective human-machine interaction.

Applied, multidisciplinary research with large scale industrial collaboration
No single entity has sufficient skills, knowledge, facilities or funding to meet the challenges of future manufacturing processes. Work in collaboration provides the necessary power in shared purpose and that, through aggregation of resources, can together achieve far more than any one individual entity could ever hope to do. Different entities with different profiles need to work together to combine their acquired knowledge, expertise and infrastructure in order to create new ideas.

Supporting Education in the field of CPS
Education should move more to the fore in order to guarantee a significant number of experts and to build awareness within the next generation of students and trainees. Establishing a cross-disciplinary study program and fostering further education programs for professionals is an important step to secure the competitive position of the European economy.

Business Models and Opportunities

Although it is difficult to forecast 20 years ahead what the future business models will be (as they are dependent on many factors) a number of observations can be made:

- Ownership is likely to become more and more decoupled from use of products. This opens up a number of new ways for sharing products, providing value and generating revenue. Here IT has an important role to play in tracking, measuring and billing.
- The trend towards green thinking (also backed up by regulation) is driving the circular economy which requires an ecosystem that supports recycling and re-manufacture. This may also link with products being used rather than being owned by consumers.
- The ability to associate information with (and within) products allows much greater levels of tracking from cradle to grave and cradle to cradle. This information can be used in a variety of ways such as for gathering data on sustainability, providing personalised products, giving guarantees of provenance, etc.

The project identified 100 business models that were classified into 10 categories. The business models that were identified were either market driven or dependent on policy and regulations. A key example of this is sustainable manufacturing which drives the development of circular economy and collaborative consumption infrastructures both at a business level and also in partnership with consumers. Market drivers towards customised products require new levels of connection between the customer and manufacturing and also flexibility within the manufacturing supply chain. Overall it is clear that companies in the future will need to be much more flexible and open minded in order to allow much higher levels of collaboration.

A feature of future business models will thus be increased interconnectivity. Although many reports highlight the move to servitisation as evidenced by the aerospace industry there is still scope and interest in other business models. It was noted that socially aware and economic business models are currently the least interesting to the manufacturing sector. For socially driven business models it is difficult to see how an idea can be monetised. For economic business models a major barrier is the legal framework that has grown up around the manufacturing industry. Well known ways of funding manufacturing enterprises exist, but the current rigid legal framework would prohibit some of the more “exotic” new approaches to financing.

Recommendations

Entrepreneurship – There is a need to develop the entrepreneurial framework and ecosystem to support increased connectivity between companies. Policy interventions may be required at a European level to support this change.

Platform Competition – A large proportion of the value chain is generated by non-manufacturing companies, e.g. Google, Uber and Amazon. There is a need for greater awareness regarding new potential competitors outside the core market.

Education – There is also a need for education. There are many well-functioning and conservative manufacturing firms which utilise outdated software. These companies fear system changes and so there is a need to build awareness for the necessity of a change. There is also a need to raise awareness of new potential competitors within the value chain, e.g. Google, Uber and Amazon.

Legal Framework – A legal framework is required to allow contracts to be rapidly set up between companies. The legislation governing the IT sector and the internet has been built up around this sector and this may not be appropriate for manufacturing. There is thus a need for legal support specific to manufacturing applications.

Insurance – A barrier too many SME's from offering services to companies is the risk introduced from liability for lost production. Here a mechanism to provide insurance would remove some of this risk.

Technology Transfer – There is also a need to transfer technology and best practices from advanced industries, e.g. aerospace, automotive, to less advanced sectors.

Standardisation – There are many challenges when offering a service based on data transfer between a client and service provider and here there is a need for standardised data formats for interoperability.

Innovation Strategies

There is a need to support both large industry and also SMEs which are the powerhouse of manufacturing in Europe. Innovation is led by industry pulling upon research that is performed both within industry and also within academia. A problem is that there is currently a "valley of death" between academic research at TRL 1-3 and industry which tends to develop from TRL 6 onwards. There is need for strategic funding to traverse this "valley of death" via funding of an "innovation pipeline" between new research outcomes and new products and processes.

This requires direct financial incentives for companies (e.g. tax relief for innovation activities) but also specific activities for research and knowledge transfer, education and training, entrepreneurship and growth. Europe is particularly strong in the ICT, Automotive and Aerospace markets and support is required for these vertical markets to maintain their position against global competition. There is also a need for action to address horizontal issues such as security and privacy.

A problem within Europe is that there are a number of very good national and regional initiatives but these are fragmented and disconnected at a European level. There is a need to create ecosystems of interrelated networks of companies and knowledge institutions across Europe and make it easier for individuals, businesses and the public sector to innovate alone, or in partnership, with the aim of strengthening innovative capability and encouraging greater investment in innovation in Europe as a whole.

A range of measures are recommended:

Competence Centres – Competence Centres driven by industry agendas should be used to encourage interaction between researchers, industry, and the public sector, in research topics that promote economic growth. They should enable research which might not otherwise take place, and facilitate interaction with industry that produces tangible economic benefits. Companies can also be exposed to and benefit from longer term, strategic research which would be too costly for them to support individually. Finally, Centres should provide an environment where companies can come together in a non-competitive manner to develop new business relationships and to learn from one another in an effective way.

Regional Initiatives – Regional initiatives should be used to allow greater direct engagement with SMEs. This is particularly important in some European countries, e.g. Italy (Regione Piemonte), where manufacturing is organised regionally. Here a bottom up approach should be used to bring all market participants together to improve competitiveness both locally and internationally, help with qualification, upgrading and diversification, test solutions, and carry out early implementations.

Clusters – Innovation Clusters are at the heart of many innovation policies within Europe, e.g. Germany. Clusters should be used to bring together industry and researchers to address specific topics or markets with the aim of creating critical mass in technological areas. Notably clusters form a concentration of interconnected companies that may well both compete and collaborate. Here Europe should support development of European-wide clusters and also linkage of existing clusters to further produce critical mass.

National Initiatives – National initiatives, e.g. Industrie 4.0 in Germany and the Catapult Centres in the UK, are being used very effectively to develop a technological lead and provide a strategic vision of the future. These well-funded public initiatives engage with larger companies accelerating research and technology in areas that are considered to be nationally important. Here it is recommended that European Union funding is used to provide linkage between these national initiatives to create a European Critical Mass in manufacturing.

Flagship Projects – In order to bring together key stakeholders, e.g. large industry and National Initiatives, it is recommended that substantial long-term Flagship research and development projects are supported that are strategically and scientifically defined and engage with many project partners across Europe.

Platforms – The future of European Manufacturing is digital. To support this Pan-European EU platform-building is needed. Platforms need to be interoperable, modular, and scalable with open and standardised interfaces. Critically for uptake they need to be affordable both from applications development and operation perspectives, with clear and easy understandable business cases. To achieve this industry commitment to European platforms is paramount. Here there is a need for relevant industry associations to lead and organise an industrial digital manufacturing forum to identify the best approaches to platform-building activities. There are three types of platform:

- **Organisational** – across stakeholder groups;
- **Technological** – organised around industrial suppliers who agree to open up part of their commercial products. Here support for integration hubs is needed to test pre-commercial solutions and act as an experimental marketplace for new product-service or business models;
- **Operational** – organised in working groups to agree on essential issues, e.g. system specification, reference architectures, or semantic interoperability middleware.

To be successful there is a need to mobilise interest and commitment by large companies to work together and develop a supporting ecosystem of SMEs and mid-caps.

Demonstrators and Large Scale Pilots – Demonstrators and Large Scale Pilots are seen as essential to show potential adopters, both SMEs and large companies, that new technologies and solutions can be exploited in the real world. It is recommended that the European Union funds a range of demonstrator activities at different scales, e.g. small-scale and large-scale pilot demonstrators, Living labs, lighthouse projects and show cases to accelerate technology uptake, provide acceptance of new technologies and engage with the full value chain.

Entrepreneurs – Notably the digitalization of manufacturing "the fourth industrial revolution" opens up many opportunities for entrepreneurs. An entrepreneurial culture needs to be developed in Europe comparable to that in the USA. There is a need for education via an entrepreneurship programme to eliminate the fear of failure and provide guidance and support for patenting, commercialisation of R&D results and business start-up.

Education and Skills – Holistic digital skills and training support need to be promoted at all levels, disseminating best practice and experience to re-skill and up-skill the workforce to the digital manufacturing level. Supporting novel industrial training methods that allow adaptability of the workforce and faster knowledge transfer need to be developed. Lifelong learning approaches are needed to continually up-skill the workforce as technology rapidly changes. An awareness is also needed at the management and factory floor levels of societal issues such as green manufacturing which will become increasingly important in the future.

Enhancing Existing Initiatives

EU innovation initiatives such as ICT Innovation for Manufacturing SMEs (I4MS) and Smart Anything Everywhere (SAE) provide a good starting point for addressing some of the issues highlighted but they should be further developed and expanded to connect together the fragmented national and regional initiatives. These should be extended to connect the different digital manufacturing initiatives and to support platform building activities that will enable the adoption of emerging digital technologies. Strong links need to be created between competence, demonstration, and innovation centres on an EU scale. Here it is recommended that showcase experiments and large scale pilots are funded to bring together key actors and critical mass. There is also a need to engage with SMEs and support innovation and transfer of technology to SMEs. The most appropriate means for achieving this is via Competence Centres, clusters and regional initiatives.

Overall the European Commission should foster co-ordination of national and regional initiatives in digital manufacturing to bring together all relevant constituencies from EU Member States. This could lead to an EU-wide network of Competence Centres.

Other issues that also need addressing are the need for a proper legislative framework as future systems would need to be "legal by design", e.g. as regards co-working of robots and humans and increased autonomy in systems. Liability issues have to be tackled with respect to potential accidents related to new ICT, but also as regards an innovative contract framework to deal with increasingly dynamic and flexible supply chains. Privacy needs to be addressed with clear guidelines on data ownership, management and exploitation to provide a level playing field across Europe. Finally, social acceptance of digital manufacturing should be promoted in co-operation with trade unions as regards issues such as employment quality and quantity, welfare, health and privacy.

Concluding Remarks

A roadmap for ICT in Manufacturing is presented that has been produced through literature research, expert panel meetings, interviews, workshops and consultation with experts across a wide range of large and small companies. Three key challenges, which impact particularly upon small and medium-sized enterprises (SME), were identified:

- A highly heterogeneous manufacturing ICT landscape and lack of interoperability
- High implementation costs
- Increasing demands from customers for flexibility, customisation and track-and-trace capability.

To meet these challenges and strengthen competitive position solutions are needed:

For facilitating shop floor production:

Big data analysis and use for quality control: Development of big data analytics for production to enable full transparency on the shop floor.

Flexible production equipment and interconnections: Enabling different products to be produced at the same time inside a production plant. This requires configurable systems that have plug-and-play modularity, tools and equipment that can be changed and reconfigured, robot collaboration and autonomous transportation solutions.

For assisting intra-company operations, decision making and information flow:

Joint Cognitive Systems for decision support: Decision Support Systems (DSS), based on multiple criteria that combine machine and human expertise.

Engineering Platform for design/operations continuum: For product and process monitoring and exchange of engineering and usage data throughout the whole product lifecycle from production to end of life.

For enhancing inter-company activities especially with its customers:

Customer and demand data gathering for analysis: To ensure that a product always meets the customer requirements and provides exactly what they want.

Product and service co-design with customer: To support increasing demand for product or service personalisation, individualisation and active customer engagement and co-creation.

For developing better supply networks:

Supply chain visibility and decision assistance: Decision support for the supply chain network to help companies synchronise, coordinate and communicate with their supply chain via a flexible, bi-directional information exchange system.

Security solutions for collaborative networks: To provide secure data storage and exchange in real-time between different companies using authentication, identification and encryption in secure platforms using robust security standards.

Other ICT solutions applicable throughout the value chain:

Open data and system integration platform for unstructured data environment - including harmonised/standardised interfaces: To enable the progression from dealing with “unstructured” data to self-descriptive to eventually dynamically integrable data sets.

Information technology (IT) and operational technology (OT) convergence (PLM-MES-ERP): To enable interoperability and ultimately the convergence of the current major business ICT applications such as ERP, MES and PLR.

Problem and context-centric display of only crucial information to the users: To provide personalised information and user centric visualisation within an organisation to aid supervisors, operators, product managers, etc. in problem solving.

Recommendations for ICT Architectures and Services

To meet these challenges and strengthen competitive position research is required on:

- Reference Architectures / Open Architectures
- System and Information Integration Architectures
- Data Capture, Storage and Analysis
- Data and Information Visualisation
- Flexible and Adaptable Manufacturing
- New Algorithms
- Modelling
- New or Improved low-cost, miniaturised smart sensors
- Interoperability and Standards
- Security
- Confidentiality
- Incorporation of psychology into ICT research
- Applied, multidisciplinary research with large scale industrial collaboration
- CPPS-Cyber-Physical production systems
- Supporting Education in the field of CPS
- Establishing Demonstrators

Business Needs and Driving Innovation

Already many initiatives exist for driving innovation. These include:

- Competence Centres
- Clusters
- Regional Initiatives
- National Initiatives
- Flagship Projects
- Demonstrators
- Living labs
- Lighthouse Projects
- Large Scale Pilots

All of these have important roles to play in technology transfer, engaging with SME's bringing stakeholders and the value chain together, developing critical mass in areas and technologies, providing strategic vision and competitive advantage in key technologies, accelerating uptake and acceptance of technologies by large and small companies through demonstration in real world scenarios.

Here it is recommended that European Union funding is used to foster linkages between these fragmented initiatives to create a European Critical Mass in digital manufacturing and technology transfer and best practices from advanced industries, e.g. aerospace, automotive, where Europe is a leader to less advanced sectors. This could lead to an EU-wide network of Competence Centres. The ICT Innovation for Manufacturing SMEs (I4MS) and Smart Anything Everywhere (SAE) provide a good starting point and should be further developed and expanded. Additionally, showcase experiments and large scale pilots should be funded to bring together key actors and develop critical mass.

A large proportion of the value chain is generated by non-manufacturing companies, e.g. Google, Uber and Amazon. To be competitive there is a need for Pan-European platform-building that will enable the adoption of emerging digital technologies considering:

- Organisational Platforms
- Technological Platforms
- Operational Platforms

Additionally, for a platform to be successful, e.g. AUTOSAR, there is a need to mobilise interest and commitment by large companies to work together and develop supporting eco-systems of SMEs and mid-caps.

The digitalisation of manufacturing "the fourth industrial revolution" opens up many opportunities for entrepreneurs and Europe needs to be ready to exploit this. Support for education in entrepreneurship is therefore particularly recommended

Similarly there is a need for digital skills and training support at all levels, disseminating best practice and experience to re-skill and up-skill the workforce to the digital manufacturing level. The workforce will need a different skill set and be more adaptive to cope with the pace of ICT technology change. Education is also needed to raise awareness at the management and factory floor levels of societal issues such as green manufacturing which will become increasingly important in the future. Social acceptance of digital manufacturing should be promoted in co-operation with trade unions considering employment quality and quantity, welfare, health and privacy.

For new business opportunities to be exploited there is a need for an innovative contract framework to deal with increasingly dynamic and flexible supply chains. The legislation governing the IT sector and the internet has been built up around this sector and this may not be appropriate for manufacturing. There is thus a need for legal support specific to manufacturing applications. Increased automation and co-working between robots and humans requires a "legal by design" framework and liability issues have to be tackled with respect to potential accidents related to new ICT. A barrier to many SME's from offering services to companies is the risk introduced from liability for lost production. Here a mechanism to provide insurance to remove some of this risk is also recommended.

Finally, in order to exploit new service ideas based on data privacy needs to be addressed with clear guidelines on data ownership, management and exploitation to provide a level playing field across Europe.

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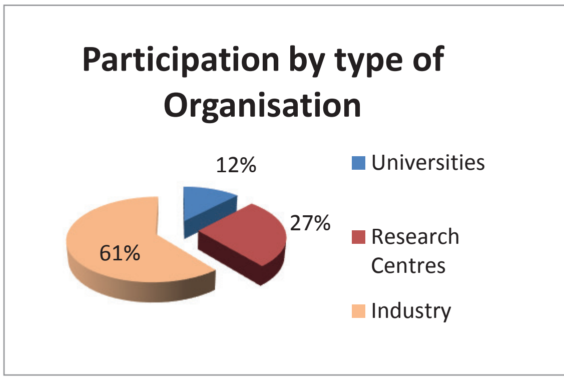

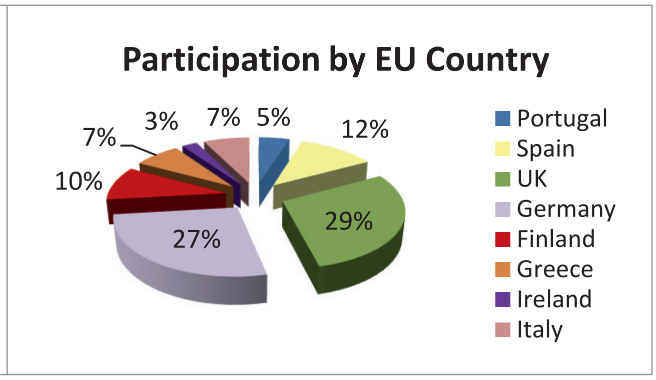

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CRITICAL MANUFACTURING

The manufacturing sector is key to Europe's competitiveness and long-term economic growth. It comprises approximately 21 % of the EU's overall GDP, however, in recent years European industry has been affected by an economic down - turn. The manufacturing sector, in particular, has had to face increasing competition from lower-wage economies and other high-tech rivals. In order to sustain and also extend international competitiveness, European firms need to foster constant innovation.

This handbook presents a roadmap for research priorities, innovation strategies and business opportunities for Information and Communication Technologies (ICT) in manufacturing. For the manufacturing sector, ICT constitute the major source of innovation, yet their potential is far from being fully exploited. So, in recent years and under the umbrella of the "fourth industrial revolution", the technical integration of Cyber-Physical Systems (CPS), the Internet of Things (IoT) and the Internet of Services in industrial processes, has led to a significant investment in novel technologies.

In light of these developments, the Road4FAME Consortium developed a strategic research and innovation roadmap for IT architectures and services in manufacturing with a specific focus on systems, 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.

The Road4FAME Roadmap serves as a strategic guide for further investment into manufacturing IT and aligns future ICT research with needs, trends and demands of European manufacturing businesses.

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Critical Manufacturing

Atos

ISBN 978-3-95663-064-4

www.steinbeis-edition.de

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