



## Deliverables 3.4 and 3.5

Final Consolidated Roadmap and Final Recommendations

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## Glossary of Acronyms

**IoT:** Internet-of-Things

**CPPS:** Cyber-Physical Production Systems

**CPS:** Cyber-Physical Systems

**MaaS:** Manufacturing as a Service

**M2M:** Machine to Machine

**UX:** User eXperience

**TRL:** Technology Readiness Level

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 aims of the roadmap generated during the project are 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.

## 1 Vision

The vision in Road4FAME is towards a future where companies come together as virtual enterprises comprised of associations of companies which cooperate ad-hoc to complement strengths, attain the capacities of large enterprises, gain the ability to react to market opportunities, research together, innovate products and minimise costs and risks for approaching new markets with new products. Large companies may bring capacity, and small companies may bring flexibility and innovation power.

Going a step beyond this, in the near future manufacturing can be provided as a service (MaaS). Here there is a need to quickly reconfigure and scale up production at short notice, to establish close information exchange with customers, i.e. integrate with other businesses, 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.

Increasingly, 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 leading 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 re-programming 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.



## 2 History of Manufacturing

**The history of manufacturing in Europe from the Industrial Revolution to the present, touching on trends of Quality Control, Continuous Improvement through to ICT and networked factories.**

Underpinning the development of modern Europe in 1780-1850 was an unprecedented economic transformation that embraced the first stages of the great Industrial Revolution and a still more general expansion of commercial activity (Barzun 2015). Two European process developments enabled this revolution, the smelting of iron ore using coke from coal (1709) and the development of crucible steel (1743). This was followed by the refinement of the steam engine (1765), giving a more flexible source of power, the harnessing of which triggered mechanisation and the resultant need for control devices.

Another important development was the Jacquard loom (1801), which demonstrated the concept of a programmable machine. The selection of the different textile patterns was determined by a program contained in steel cards in which holes were punched. The concept of programming a machine was further developed later in the 1820s when Babbage proposed a complex, mechanical difference engine that could perform arithmetic and data processing. Although never completed, this device was the precursor of the modern digital computer (Goover 2015).

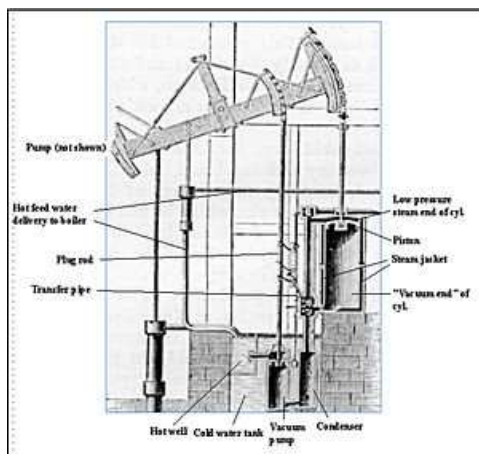


Figure 1: Milestones of technological development

A) *The major components of a Watt pumping engine (1765)*<sup>3</sup>

B) *Jacquard punched card loom machine (1801)*<sup>4</sup>

European manufacturing was further strengthened by two significant advances. These were in England and France in the early 1800s and involved accurate measurement and making to a dimension, which underpinned the development of the first machine tools and resulted in the training of a generation of mechanical craftsmen.

<sup>3</sup> Image Source: [https://en.wikipedia.org/wiki/Watt\\_steam\\_engine](https://en.wikipedia.org/wiki/Watt_steam_engine)

<sup>4</sup> Image Source: <http://www.computermuseum.li/Testpage/Jacquard-Punched-Card-Loom.htm>

From 1850 onwards European manufacturing industry developed based largely upon the availability of natural resources of water, coal and iron ore, and included textiles and metal manufacture. The invention of the internal combustion engine followed and the origins of the automotive industry are rooted in the development of the gasoline engine in the 1860s and 1870s. In the USA, in the middle to late 1800s, small arms manufacture was based on interchangeability. Specialised machines were used to produce accurate components in high volumes, demonstrating huge increases in productivity, and specialisation principles were applied to the whole manufacturing system in the early 1900s.

During the period 1870-1914, established sectors included textiles, iron and steel manufacture, shipbuilding, engineering, and boot and shoe manufacture (Ackrill 1987). At this time the engineering industries worked the metal by hand or machine tools. Technical progress had been largely incremental and the skill of both workers and managers was acquired by apprenticeship. The engineering revolution was brought about by the development of high-accuracy machine tools including lathes, drills, milling and grinding machines. Powered by hand or foot at first, then later by belts connected to steam engines, the rotary machine tools could be set up to carry out pre-determined operations to produce identical pieces in large numbers for interchangeable assembly. After 1890 came turret and capstan lathes, milling and grinding machines that could be set by craftsmen but operated by semi-skilled labour.

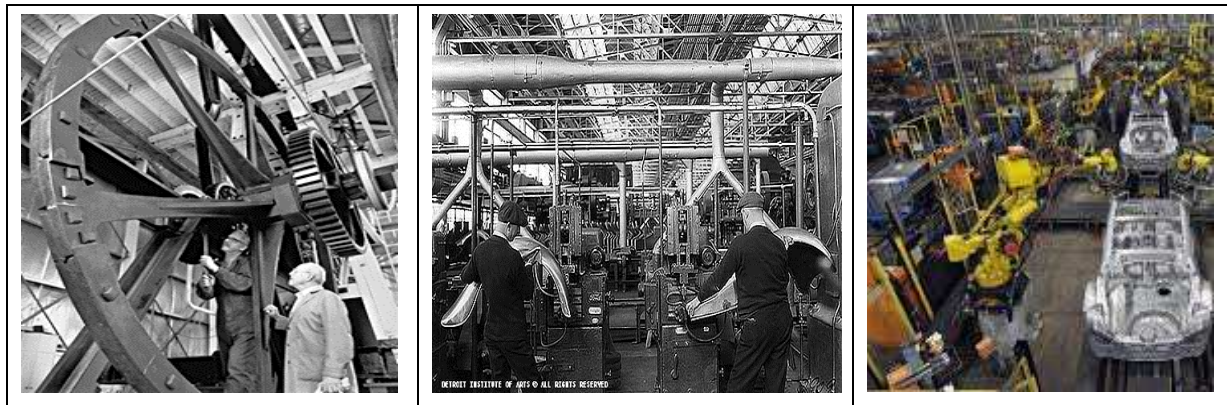


Figure 2: Technological progress

A) Boulton & Watt Rotative engine(1785)<sup>5</sup>

B) Ford's River Rouge Factory<sup>6</sup>

C) Modern Automated Car Factory<sup>7</sup>

By 1914 the military armaments and textile machinery companies in Europe had made significant engineering improvements and were producing innovative products. In the light engineering industry, European innovations included the bicycle and refrigeration. Manufacturing developments

<sup>5</sup> Image Source: <http://www.powerhousemuseum.com/insidethecollection/tag/rotative-steam-engine/>

<sup>6</sup> Image Source: <http://www.clemson.edu/caah/history/FacultyPages/PamMack/lec122/aline.htm>

<sup>7</sup> Image Source: <https://dylandehond.wordpress.com/2013/05/>

in automotive and chemical industries were significant in this period. By 1913 three major German companies produced almost 90 percent of the world supply of synthetic dyestuffs and sold about 80 percent of their production abroad (Aftalion 1991).

Between 1914 and 1939 there was considerable economic and political uncertainty and the established industries all experienced fluctuations in output and sales. In the engineering industry, new areas included office equipment, components for domestic appliances and continued developments in transport. Automotive manufacturers adopted moving assembly lines and partial automation of engine and body sections was introduced.

During the period 1939-1951 there was initially an increased focus on European machine tool industries for newer engineering products. Later on, insufficient attention was paid to applied science, technology, developmental and production engineering in some European countries, leading to a slowdown in productivity growth and a lack of sustained output of quality products.

In the last 50-60 years (since 1955/1965) manufacturing industry has undergone significant change as demonstrated by shifts in the European manufacturing research agenda, with four generations of research focus apparent (Rolstadas 2007):

- Machine focus – improving the performance of a single process element
- Factory focus – industrial automation, robotics, CNC, flexible manufacturing, operations process planning, CAD/CAM, CIM and intelligent manufacturing
- Supply chain focus – digital solutions for planning, control, management and business operation in the extended enterprise
- Product lifecycle focus – extended product view from design to end-of-life

These shifts have been promoted by major changes in manufacturing industry philosophy and technology over the period, starting with concepts such as Quality Control and Continuous Improvement. Deming's work in Japan in the 1950s disseminated the concept of statistical quality control, the link between quality and productivity, and the benefit of ongoing interaction between research, design, production and sales in promoting product quality and customer satisfaction (Deming 1982). Building on this the Japanese developed systematic continuous problem solving approaches and in the early 1980s European companies began implementing continuous improvement processes, which are now widely spread in manufacturing industry. Such approaches are increasingly being applied in product development activities (Lodgaard et al 2012).

The development of integrated circuits in the 1960s led to miniaturisation in computer technologies, leading to today's microprocessors, and enabling smaller machines. Along with advances in computer technology, there were also significant improvements in storage and sensor technologies, giving measuring devices for feedback in automatic control systems and allowing machine vision, as required for part identification, inspection and robot guidance. This drove increasing manufacturing application of automation and robotics from the 1970s onwards. More recent advances in network computing and internet technologies over the last 20-30 years have led to networked factories in which people and machines use smart systems to communicate with each (Shi & Gregory 1998). As part of this concept, companies can introduce Cyber-Physical Systems (CPS) to create more versatile

manufacturing conditions while increasing the flexibility of their production and logistics (e.g. Fraunhofer 2015, BCG 2015). In addition, these technologies have accelerated business activities (Iung & Monostori 2007) enabling companies to shift their manufacturing operations from the traditional factory integration philosophy to a supply chain-based e-factory philosophy (Lee 2003). Digital manufacturing is anticipated to be the next industrial revolution combining integration of CPS networks with the Internet of Things (IoT) within companies, supply networks and product users (Industrie 4.0)

Other major changes in manufacturing industry were sparked by Manufacturing Strategy research (including Skinner 1969, Hayes and Wheelwright 1984) and its implementation in the 1980s and 1990s that stimulated the development of manufacturing strategy formation processes to tackle factory effectiveness issues and laid the foundation for later ICT systems development and system efficiency.

The United Nations has published its annual World Investment Report since 1991 (UNCTAD 1991) and in the last 30 years it has been increasingly realised that the economy has become global. One implication of this is the different roles of factories in multinational corporations (MNCs) as summarised by Ferdows (1997), and it is recognised that his work enlarged the boundary of the Production Operations Management discipline to include dispersed networks.

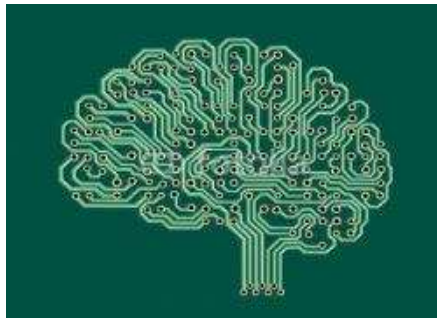
In comparatively high wage economies, such as in Europe, there is a need for manufacturing to change radically to remain globally competitive. This has resulted in the rise of the knowledge-based economy and high value manufacturing (TSB 2008) and a focus on high-value, knowledge intensive goods. Hence, the emphasis of activities is not just on production, but embraces provision of lifetime service around a manufactured product. Continued automation of physical and information processes will drive efficiency improvement, and the business model will be increasingly specialised, with outsourcing of non-core activities. This will result in the value chain becoming increasingly complex and international, resulting in global value networks.

The most recent change is the increase in sustainability related awareness that has widened thinking of products and services, and the processes that make them, from a narrow producer/consumer oriented view to an eco-system level view where the whole lifecycle of a product is considered and product data managed from design to end-of-life (Garetti et al 2007).

Building on these developments, advanced manufacturing paves the way for the future of industry in Europe (Europa 2014) and can be seen as having three main strands:

- High performance manufacturing - flexible precision, zero defects via high precision machine tools, advanced sensors and 3D printing;
- Sustainable manufacturing technologies - to increase manufacturing efficiency of energy, materials and reduced emissions;
- ICT enabled intelligence - integrating digital technologies into production processes and between elements in the wider supply chain.

### 3 Developments of ICT Innovation in Manufacturing



In the past 70 years the mathematical theory of control systems has developed steadily. In 1946 the ENIAC (Electronic Numerical Integrator and Calculator) and in 1951 the UNIVAC (the Universal Automatic Computer) developed advanced control functions in automation and the first numerical control (NC) machine tool was demonstrated in 1952 in MIT.

Automation in the motor industry continued with the first robot at General Motors in 1961.

IBM was the first company to offer a series of computer products that were compatible, which meant that users could upgrade their systems with minimal interruptions to the computing work of their firms, such as manufacturing products (Cortada 2004). Disc drive information storage devices proved integral to these systems in terms of quick information retrieval and making online systems technically and economically feasible, leading to whole new generations of applications in the 1960s and 1970s. Standardisation across all forms of technology encouraged the adoption of computing. The pattern of incremental improvements in computers and their peripheral equipment (data entry and output devices) already evident in the 1950s continued through the 1960s and 1970s. Online systems and packaged software appeared (e.g. for accounting and manufacturing applications). Companies and governments began linking computers to telephone lines to carry out work across regions.

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). In terms of technology enablers examples of ICT application 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 manufacturing (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

The industrial revolution continues, accelerated by digital technologies. ICT-based solutions applied across the manufacturing process chain helps to make manufacturing more efficient and sustainable while also allowing the creation of virtual value chains independent of geographical location (Europa 2013). They can also help manufacturers address current markets and customer demands and exploit new or emerging markets.

Future manufacturing is expected to exploit advances in wireless sensor technologies, machine-to-machine (M2M) communication and computing, that would enable to track and trace each individual part of the production and monitor the individual phases. Together, an internet-style network of interconnected, intelligent machines is termed Cyber-Physical Systems (CPS) (see figure below). This 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*”<sup>8</sup>. Networked CPS can offer additional features like dynamic reconfiguration, continuous evolution, partial autonomy, and emerging behaviour of CPS networks<sup>8</sup>. 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.

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<sup>8</sup> <http://www.cpsos.eu/wp-content/uploads/2014/09/CPSoS-flyer.pdf>

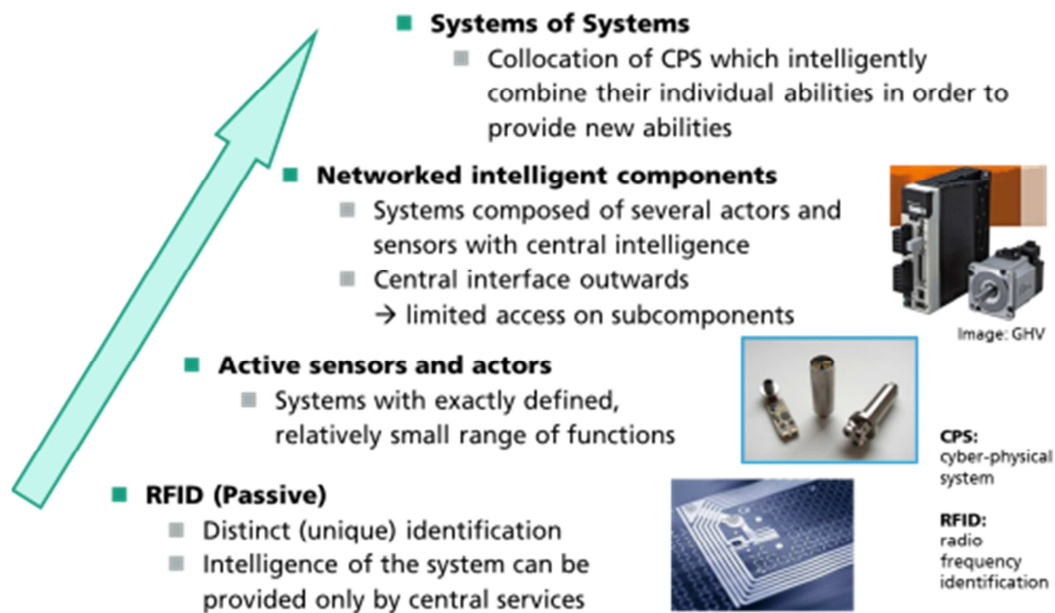


Figure 3: CPS Stages of Intelligence (© Fraunhofer IPA)

The importance of ICT in manufacturing has been recognised by several national industrial policies, for example Industrie 4.0 in Germany, High Value Manufacturing in the UK<sup>ii</sup> and Smart Industry in the Netherlands<sup>iii</sup>. In Industrie 4.0 is stated as the 4<sup>th</sup> industrial revolution and is based on the technical integration of “Cyber-Physical Systems” (CPS) in production and logistics as well as the application of internet of things and services in industrial processes”. This includes any increase in the value that manufacturing businesses offer, new and changing business models and the incorporation of services and work organisation. The schematic below shows previous revolutions in manufacturing, initiated by the steam engine, assembly-line work, and electronics and automation.

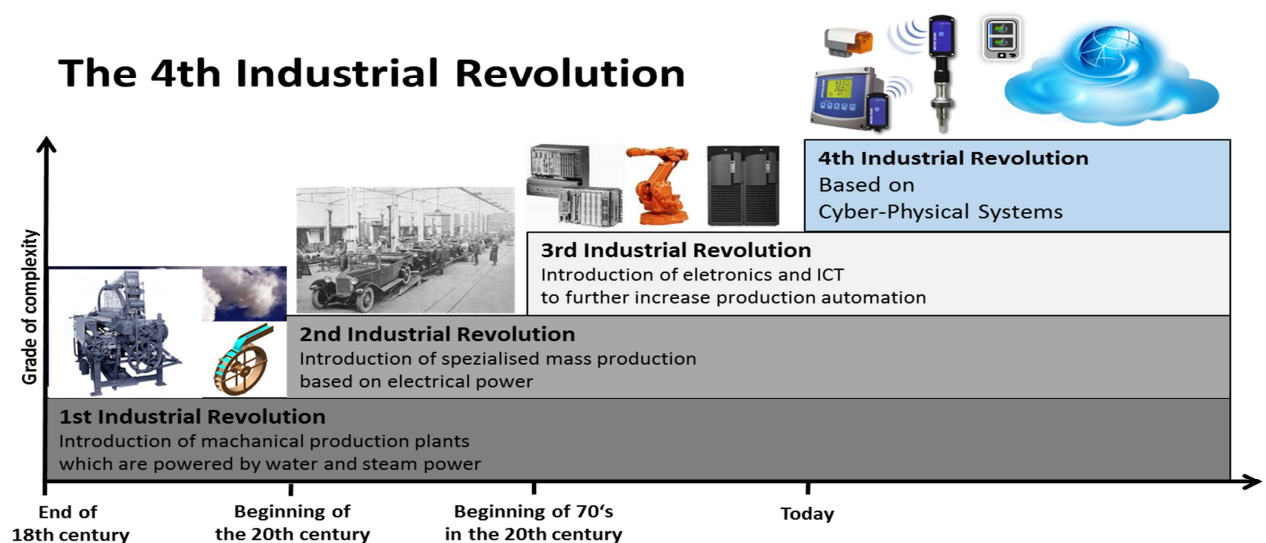


Figure 4: Stages of the industrial revolutions across recent history (© Fraunhofer IPA)

## 4 Current Manufacturing Needs and Barriers for the Digitisation of Manufacturing Businesses

Due to globalised markets and the increasing competitive pressure, manufacturing companies seek to optimise their business processes where possible. Frequently, this creates also the need to innovate with regards to their manufacturing IT. But IT innovation at manufacturing companies is not only driven by competitive pressure. For many manufacturing companies, the driving force for IT innovation is ever stricter requirements imposed by large buyers. To these companies, *affordable* manufacturing IT solutions to meet the imposed requirements are crucial. A third driver for manufacturing IT innovation besides competitive pressure and stricter requirements are new standards and regulations.

Nevertheless, 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. Frequently, IT innovation originates outside the field of manufacturing IT. In the past, manufacturing IT has benefitted from development of the IT technologies directed to consumer markets, an example being the Ethernet technology. Thus, in search for future manufacturing IT innovation, consumer IT markets are worth paying attention to. One can think of consumer IT markets as fulfilling something like a *sandbox function* for future manufacturing IT. Because of comparatively low requirements and the much greater market pull and volume on consumer markets, very advanced technologies can be seen at work very early in this area.

Over the last decades, many companies have been implementing point-solutions, each bringing a specific feature or fixing a specific issue. As a result the IT manufacturing landscape is highly heterogeneous often likened to a “wild garden”. While these IT landscapes are already costly to administer, further addition of capabilities becomes even more costly because they have to be fitted into an existing infrastructure. This is a main reason why manufacturing companies are usually well behind the latest manufacturing IT technology. Without approaches to overcome this situation, or lessen the impact of it, manufacturing IT innovation will always be doomed to happen slowly. So, 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 the very high implementation costs.

**More than ever, manufacturing is *based* on IT and thus IT security becomes increasingly important as well. There are many well publicised cases of big IT systems failing and costing a lot of money.** Today, concerns about security and privacy are the number one show-stopper for manufacturing IT innovation, an issue just as urgent as the high-implementation-cost-problem described above.

### Implications and requirements for future manufacturing IT solutions and architectures

To manufacturing companies, especially smaller ones, *affordable* manufacturing IT solutions are crucial to keep their competitive position. While the required manufacturing IT solutions as such are usually available today, they are not available at a moderate cost and thus frequently beyond reach of smaller companies who are struggling to keep up with the imposed requirements.



Solutions need to come at low setup cost, and must be easy to integrate with the existing IT landscape. These must not interfere with already running processes, so seamless (and low risk) integration is required. New models of renting software and cloud based approaches may present opportunities e.g. pay for use type models.

A flexible IT architecture is required which allows integration with and alongside existing systems (we are adding to 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 it provides. Opportunity here is for service providers to provide a pay for use service. The infrastructure used – e.g. cloud, may not actually be on site or owned by the factory. This is a far more cost effective approach for SME's who may be producing for larger companies.

### Most important challenges and needs

**Flexible manufacturing:** Arguably the most important need for manufacturing businesses is flexibility. Several manufacturing companies described flexibility as the need which has most strongly increased in importance over the past decade, a trend, which they anticipate to sustain. The need for flexibility is driven by the trend of shorter product life-cycles which, in turn, is caused by increased competition due to global markets. Another important driver for the need for flexibility is the increasing demand for customised products as well as **anticipate and forecast demand changes and adapt internal operations accordingly** which can be observed on many markets. Ironically, 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 plant or company boundaries, **to attain highest levels of flexibility at the plant level, the upstream supply chain must be flexible as well.** But the need for a flexible supply chain goes beyond realising flexible manufacturing. 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 as manufacturing assets are used 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 already at numerous locations. But as **data and information** are acquired by a multitude of separate systems are often not **joined, correlated or shared.** Manufacturing companies already have lots of data available acquired at the shop floor but often struggle to derive information from it, i.e. to correlate/interrelate 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 desire to apply mobile devices in a manufacturing context. A production manager who will be able to see manufacturing data in real-time on his smartphone or tablet is only one of the less interesting use cases. Mobile devices will become most powerful once they constitute a new form of human machine interface, enabling the worker to operate not just a single machine but interact with the entire production equipment, get 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. Mobile devices in manufacturing are a move away from the central decisions made in a control room, rather, an order or a warning would be sent directly to the right person who can then take action. In the future, the need for mobile devices as human machine interfaces is expected to increase for they enable human beings to interact easily even with complex systems, and support informed decision based on real-time information. Such devices are what integrate the human being in an Internet of Things and allow him to interact with it.

## 5 ICT in Manufacturing Roadmap

The ICT in manufacturing roadmap was developed over a period of 29 months following a series of activities such as literature research, interviews, workshops and post-analysis. In total over 50 public documents, reports and roadmaps in the domain were consulted, more than 40 interviews with manufacturers and ICT providers were held and seven workshops were organised to review, prioritise and explore the most important needs, solutions and technologies required by the European manufacturing industry.

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

### External and Internal Drivers

- **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.

This layer provides external and internal drivers and trends – ‘why’ things are done.

### Solutions

- **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**

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 and the functionality required to support the stated manufacturing business requirements now and in the future.

### Research and Resources

- **(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/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.

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

The roadmap was developed over a period of 29 months. Content was collected initially through desk research, literature review and consultation of other related roadmaps in the domain. The content was enhanced through several face-to-face interviews predominantly with manufacturers and was reviewed, enhanced further and prioritised through five roadmapping workshops with several European manufacturers, ICT providers and academics. The full list of contributors to this roadmap is shown in Appendix 1. The ICT in manufacturing roadmap is shown in the figure below.



## 6 ICT Solutions

Road4FAME is focusing on ICT architectures and services for the manufacturing industry. Eleven ICT solutions were identified and evaluated within the Road4FAME project to address current manufacturing needs, trends and drivers. These could assist European manufacturing companies optimise their business operations, remain competitive, maximise the value they get from their networks and utilise their ICT systems better to improve their operations. The eleven solutions are summarised in the following sections.

### 6.1 Open Data and System Integration Platform for an Unstructured Data Environment that Includes Harmonised / Standardised Interfaces

Many current manufacturing systems contain a multitude of equipment, processes and software solutions. This can create bottlenecks when problems arise that require quick decisions or when new systems are introduced into the manufacturing environment that need to be integrated with existing infrastructures. How to reduce integration and set-up costs for new tools and equipment especially when these are incorporating novel ICT components and systems is a major issue.

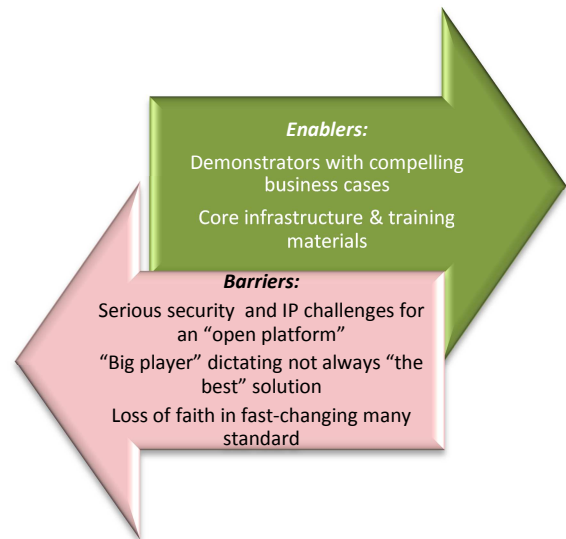
A possible solution to this is the development of an integration platform that facilitates the collection of “raw” (i.e. unstructured) data from different sources and integrates it into pre-defined (contextualised) fields to facilitate review and decision making.

This solution would enable the progression from dealing with “unstructured” data to self-descriptive to eventually dynamically integrable data sets. It includes semantics on data/information, methodologies for data semantic enrichment, open standards and flexible solutions for change management. At the end such platform should provide a “one-click integration” for manufacturing systems with comprehensive site-wide consistency and facilitate the faster development of complex, customisable products.

The advantages of such a platform will be numerous such as:

- Improved decision-making regarding both time and quality
- Potential for one-click integration of manufacturing systems
- Common/standard of knowledge representation projects
- Fewer errors due to manual format/language transformation and reduction of engineering efforts
- Consistency and context management also allowing inter-context management
- Creation and availability of sustainable knowledge models
- Tools with user-acceptance focus

**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 on 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 info from component design, production schedule, stock control and ordering systems as all these run on different software packages.



The **implementation challenges** are to develop a core infrastructure and 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.

The links of this solution to manufacturing needs and required research and technologies are summarised in Appendix 2. The roadmap for this Solution is shown in the figure below.

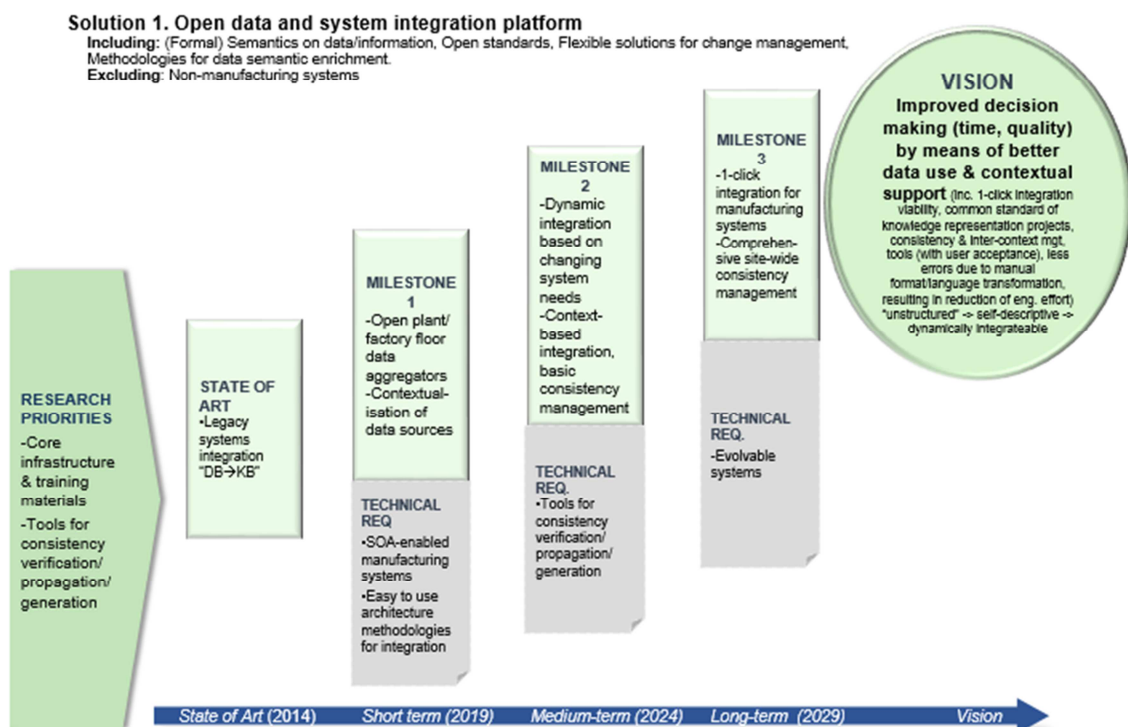


Figure 6: Roadmap for ICT Solution 1: Open data and system Integration platform

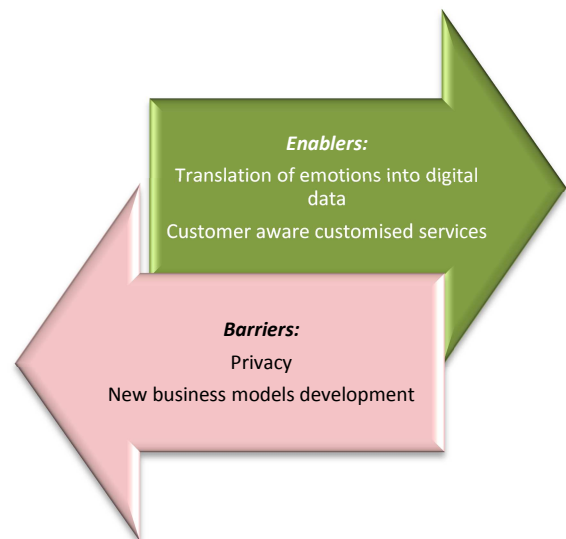


## 6.2 Customer and Demand Data Gathering and Analysis

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 on how to design and produce a new product or reconfigure an existing one that always meets customer requirements and provides them with exactly what they want. So the big challenge is having a production which is flexible enough to produce high volumes of personalised retail products.

An important first step to 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 happen through standard feedback methods, but gradually data from social networks can be used and eventually a fully context-aware data collection system can be developed, implemented and used within companies.

**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.*



The **implementation challenges** are research around data mining and decision making. It will be also important to research aspects of business engineering and business model development to facilitate the implementation of such a solution.

The roadmap for this Solution is shown in the figure below.



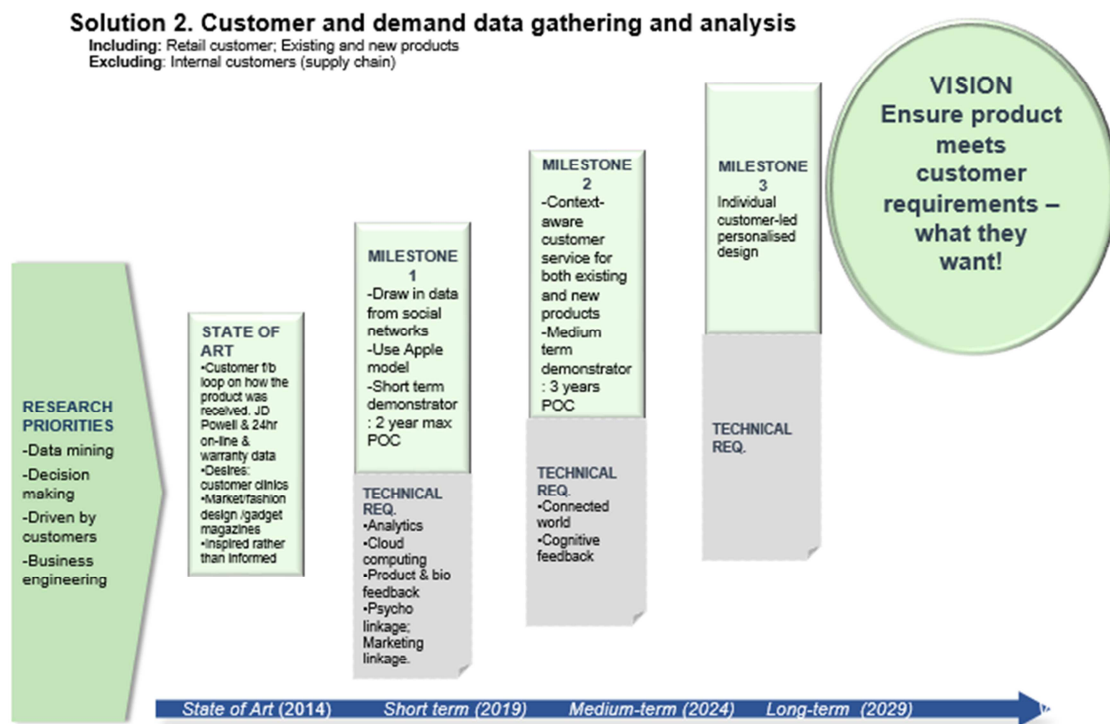


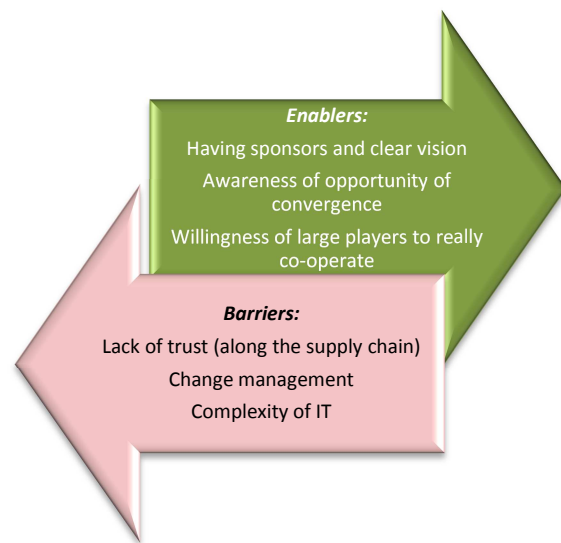
Figure 7: Roadmap for Solution 2: Customer and demand data gathering and analysis

### 6.3 Information Technology (IT) and Operational Technology (OT) Convergence: Integrated Architecture of Product Lifecycle Management (PLM), Manufacturing Execution Systems (MES) and Enterprise Resource Management (ERP)

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. 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 potentially increasing the costs of innovation and weakening the market position of the business.

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 or a fully integrated all-encompassing engineering tool chain. 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.

**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.).*



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

The roadmap for this Solution is shown in the figure below.

### Solution 3. IT-OT Convergence

**Including:** Entire product life-cycle; Entire supply chain; Cyber physical systems; Lean continuous improvement;  
Major business applications – MES, PLR, ERP; Information flow  
**Excluding:**

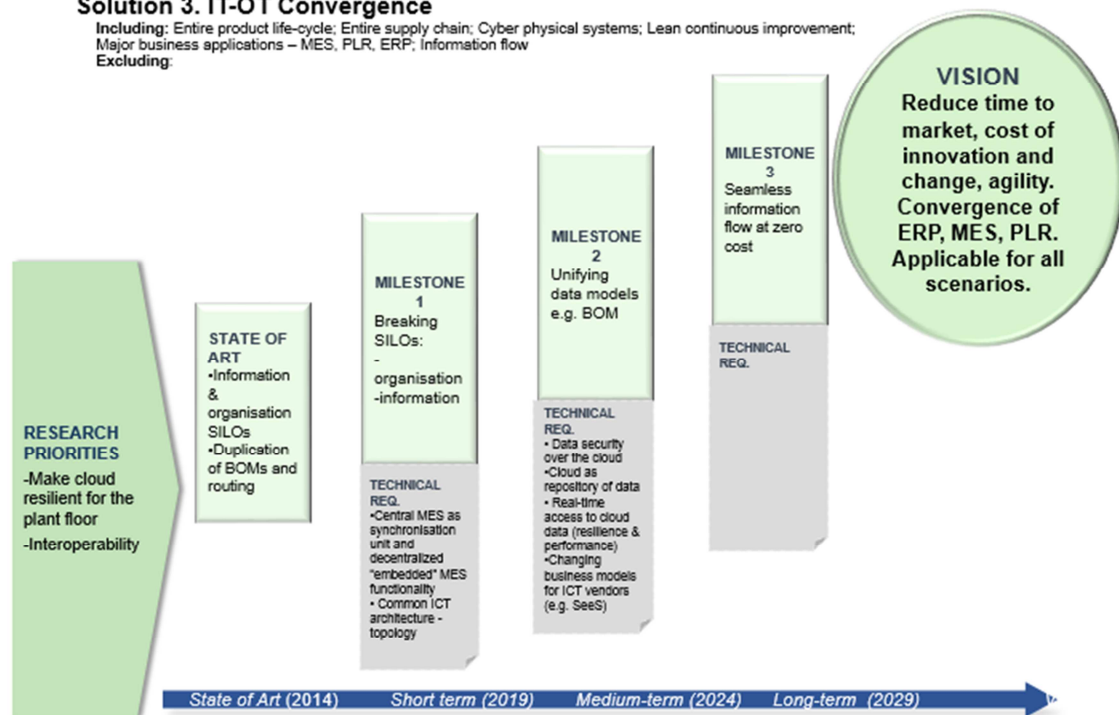


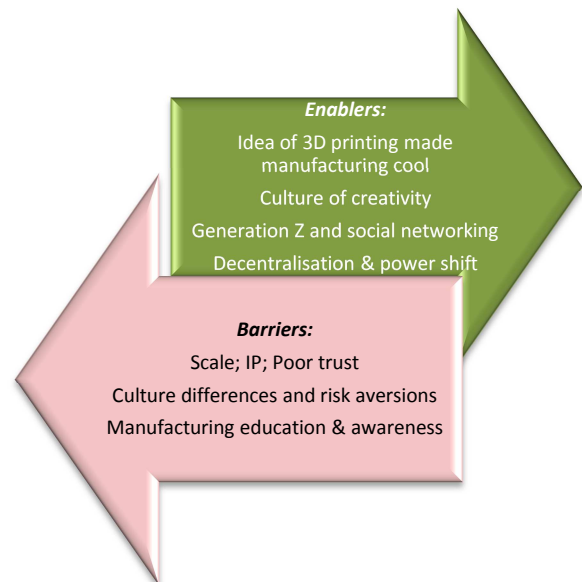
Figure 8: Roadmap for Solution 3: IT-OT Convergence

## 6.4 Product and Service Co-Design with Customer

Current socio-technological trends in manufacturing foresee an increasing demand for product or service personalisation, individualisation and active customer engagement and product or service co-creation. Manufacturers in developed economies 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. An innovative ICT solution is required to support such a shift in current manufacturing practices, which are mainly a "push" model of product to the market, have predominantly a cost reduction focus and are based on simulation and process optimisation.

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.

**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 (hardware & software), working hours and customer support systems to provide its clients with the products they require while remaining profitable.



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

The roadmap for this Solution is shown in the figure below.

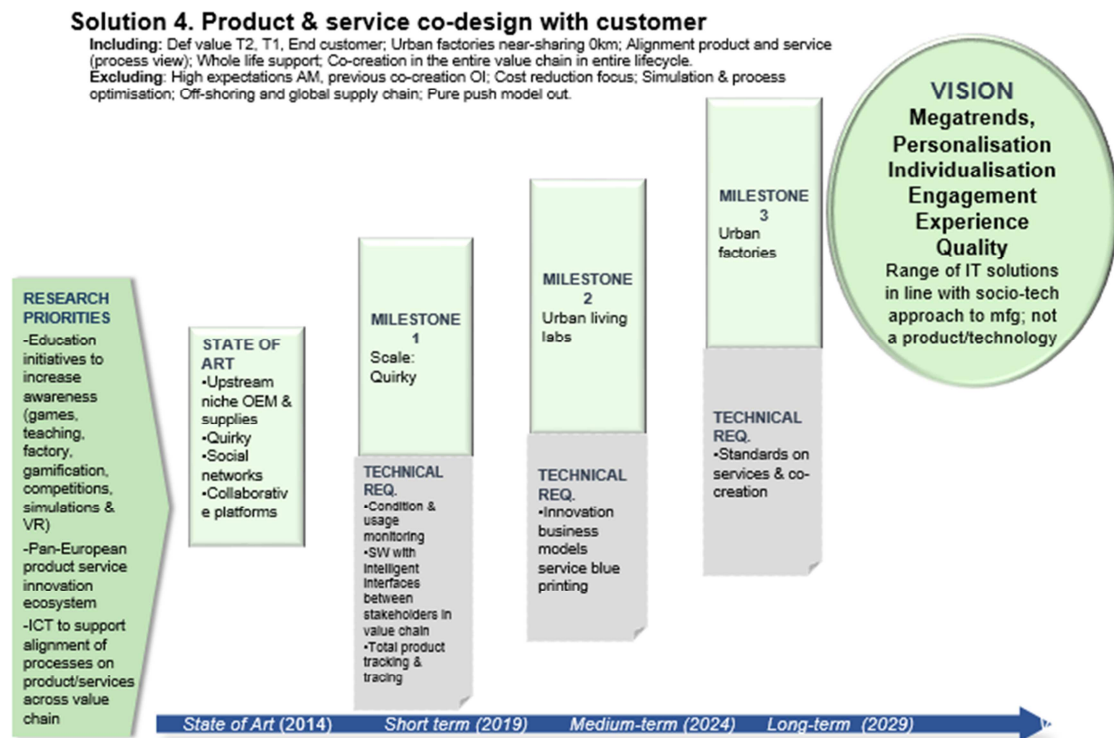


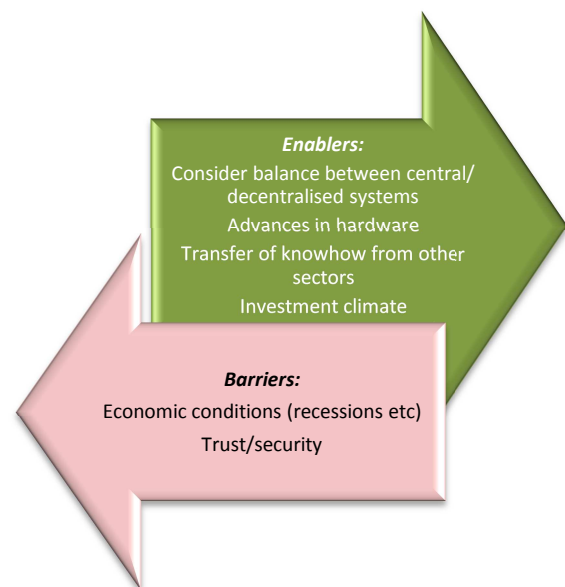
Figure 9: Roadmap for Solution 4: Product and service co-design with customer

## 6.5 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 to provide more data that is reliable and 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. 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.

Currently data is mainly produced in isolated steps from all different production processes. 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, logistics and equipment monitoring can be collected and used to aid quality decisions.

**Case study:** A large Infra-red equipment manufacturer produces specialised electronic instrumentation for fire brigades around the world. The instruments are utilised in harsh conditions and the fire brigades require that each instrument performs perfectly for up to five years as operational problems can be fatal. 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.



The **implementation challenges** are around adding semantic content to unstructured data and being able to develop a responsive visualisation of data, integration of information, real-time data mining, event driven database systems and streams, fusion of systems and new ICT architectures (hybrid systems).

The roadmap for this Solution is shown in the figure below.

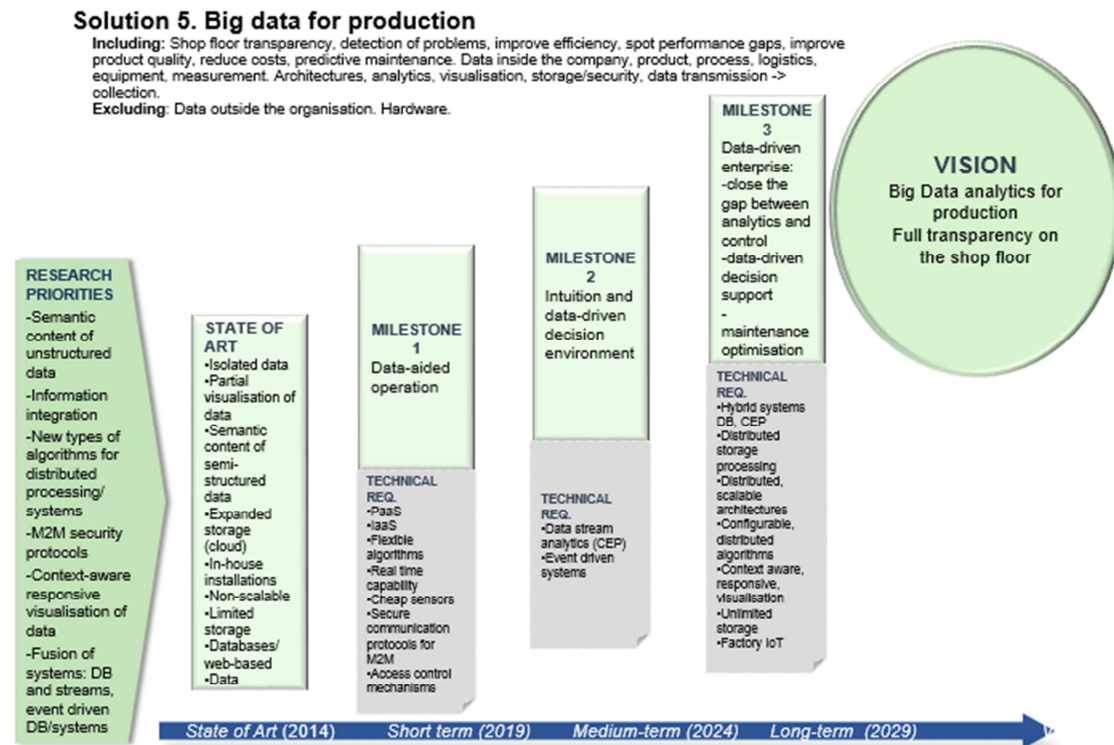


Figure 10: Roadmap for Solution 5: Big data for production

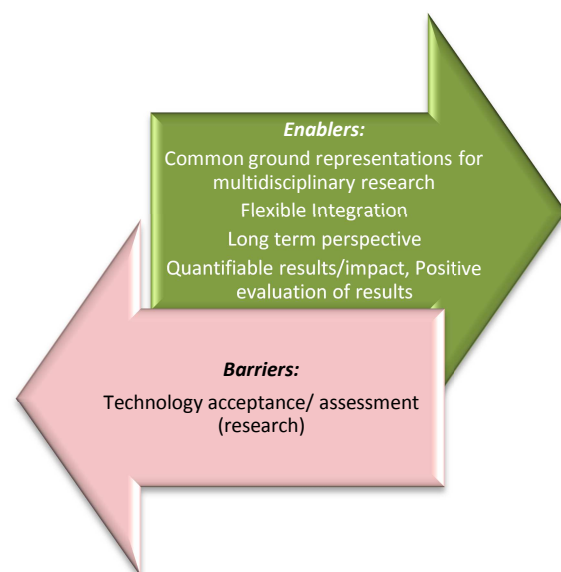


## 6.6 Joint Cognitive Systems for Decision Support (DSS)

This ICT solution is for the development of an intra-company Decision Support System (DSS) that combines machine and human expertise to facilitate decision making. In its core, 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. It goes beyond classical ergonomics and close-loop automation, instead is based on socio-technical systems engineering. Currently, decision cycles are static. The aspiration is to develop a DSS that is highly flexible and infinitely evolving with the needs of the business.

For the design and implementation of such a system a range of different technologies and domains need to be developed and integrated such as human-centric machine learning interaction design, incorporation of Use eXperience (UX) into mathematical modelling and tacit knowledge modelling, process optimisation reasoning, formal specification of a shared conceptualisation (i.e. semantic ontologies) and mainly visualisation and visual languages. Especially visualisation of 3D simulation environments as well as virtual and augmented reality, are critical for assessing process and information flow, mapping of concepts, and resources and expert knowledge.

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

The roadmap for this Solution is shown in the figure below.



### Solution 6: Joint cognitive systems for decision support (DSS)

**Including:** Socio-technical systems engineering, Human & technology learning & evolution; Human centric machine learning interaction design; UX of mathematical modelling, Accessibility; Tacit knowledge modelling, process optimisation; Reasoning, visual languages, semantic ontologies; Visualisation: causality, rules configuration, uncertainty, process flows, information flows, expert knowledge / concept mapping resources  
**Excluding:** Classical ergonomics, closed-loop automation; Visualisation: 3D simulation environments, Virtual reality, Augmented reality

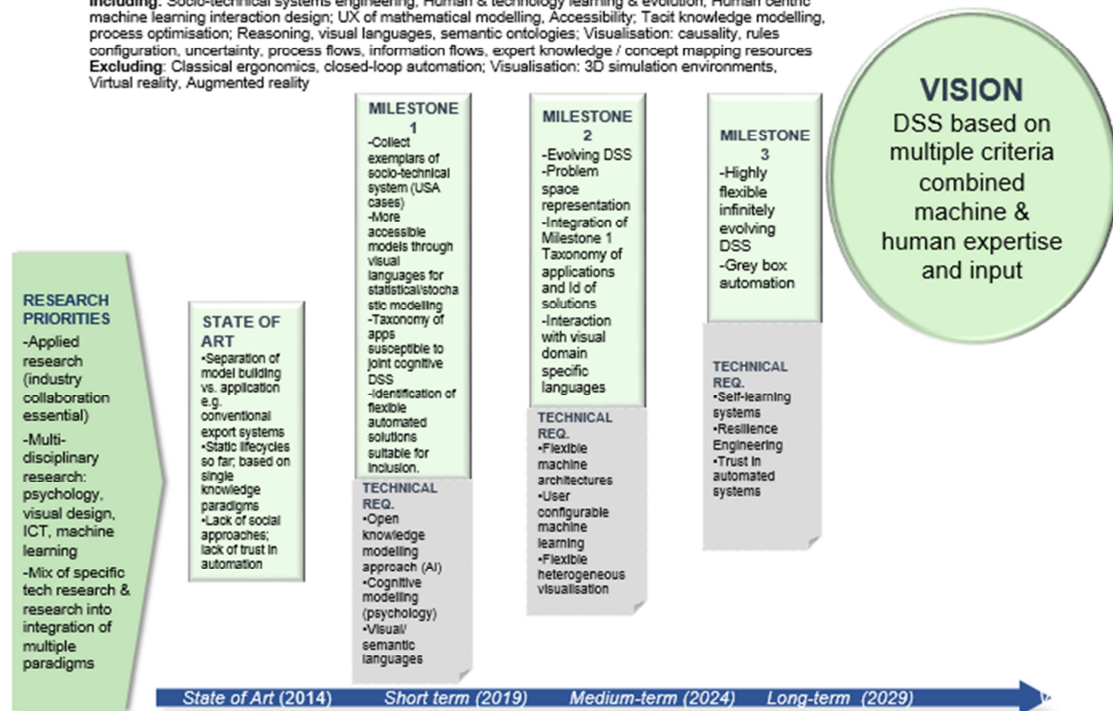


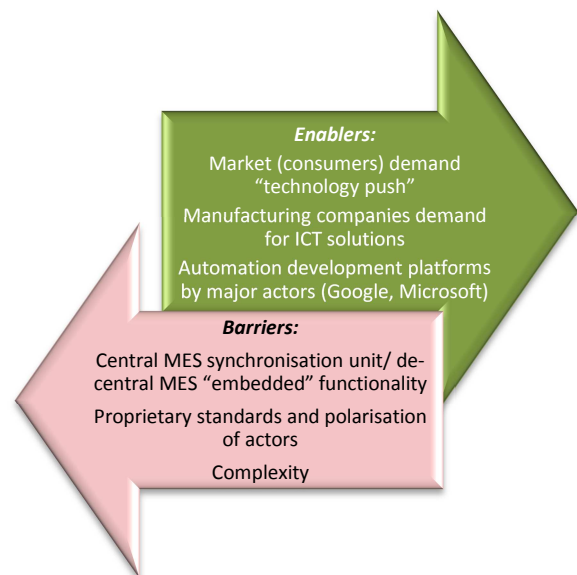
Figure 11: Roadmap for Solution 6: Joint cognitive systems for decision support (DSS)

## 6.7 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 around 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.

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.

**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.



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

The roadmap for this Solution is shown in the figure below.

### Solution 7. Flexible production equipment and interconnections

**Including:** Configurable systems, plug 'n' play modularity; Robot collaboration; Autonomous transportation solutions (e.g. AGVs with dynamic mapping and navigation, changeable conveyor systems); 3D printing; Tool/equipment changeovers and reconfigurations.

**Excluding:** Adaptable production place (e.g. robot connected to "learning algorithms"); Internal logistics.

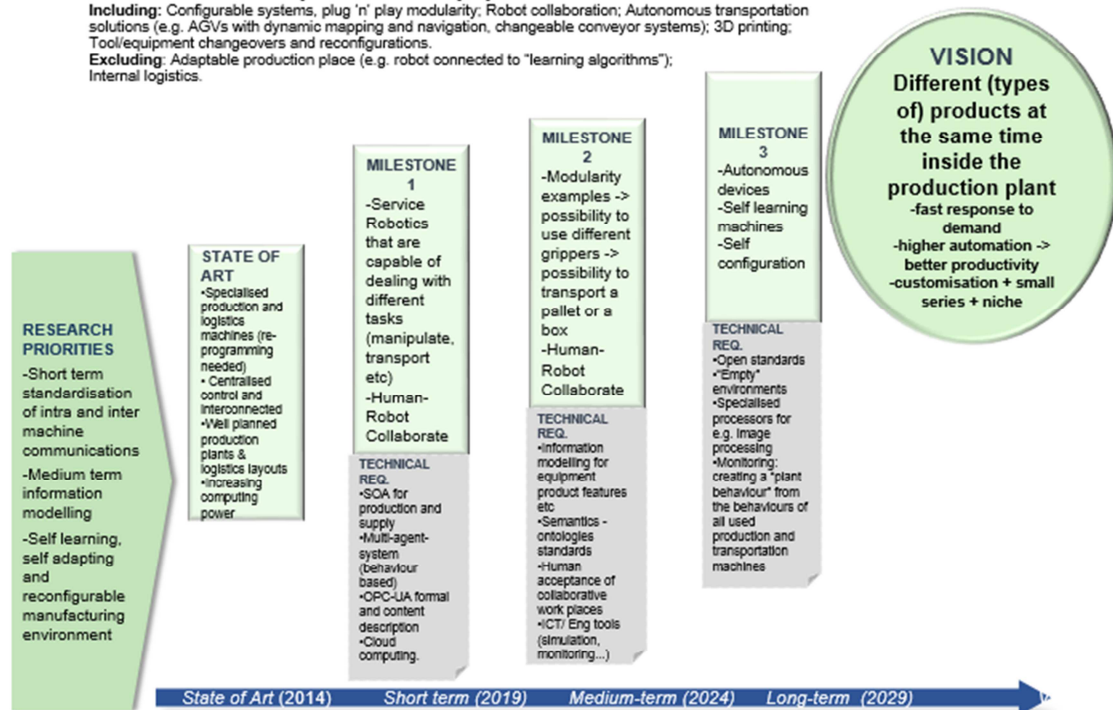


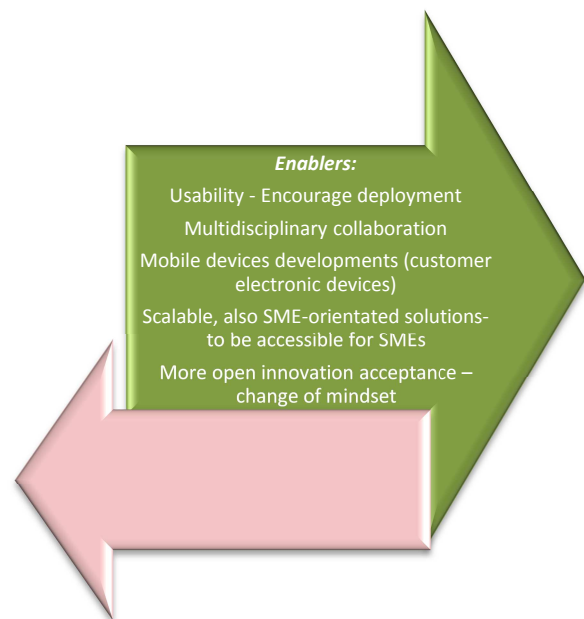
Figure 12: Roadmap for Solution 7: Flexible production equipment and interconnections

## 6.8 Problem and Context-centric Display of only Crucial Information to the Users

Visual management systems already exist in many manufacturing environments. These normally enable faster communication and improve adhesion to key processes especially in situations where cultural and/or language barriers are high. 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.

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, especially around cost reduction, increasing safety and improving the performance of the operators.

**Case study:** *A manufacturer of household cleaning products operates a continuous production line seven days a week and employs several hundred people from all over Europe. Health and safety protocols are paramount throughout the company and particularly in the production area as corrosive and flammable liquids are in frequent use. Although the company spends long time training 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 **implementation challenges** are around the integration of smart components for big data collection, analysis and visualisation, human-centric adaptive interfaces and research in new modalities for interaction, developing contextual awareness for different manufacturing environments, standardisation of interfaces and communication potentially including self-configuration.

The roadmap for this Solution is shown in the figure below.

## Solution 8. Problem and context-centric display of only crucial information to the users

**Including:** Data gathering: real-time data, context data, historical data; Context aware analysis of data; Simulation processes; To whom – supervisors – quality etc, to managers – strategic, to operators, maintenance, product managers, new employees; Short term scheduling activity; supply chain data  
**Excluding:** Big data (taken as available); Public service, security service people; Customer data requirements.

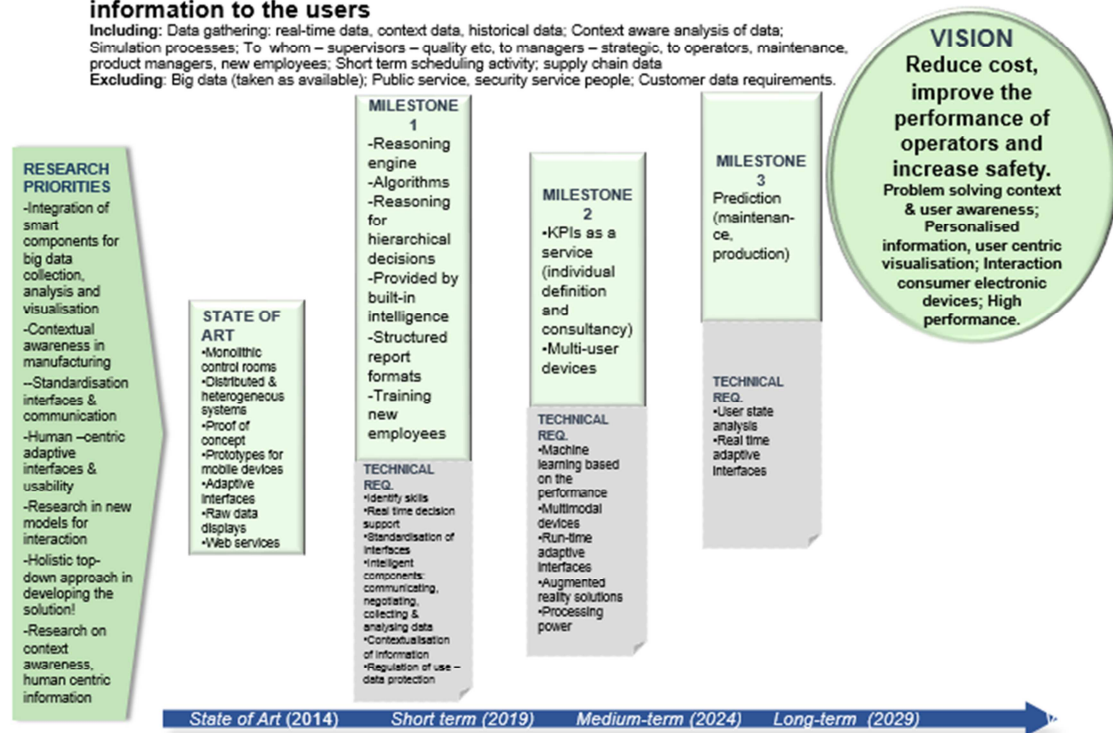


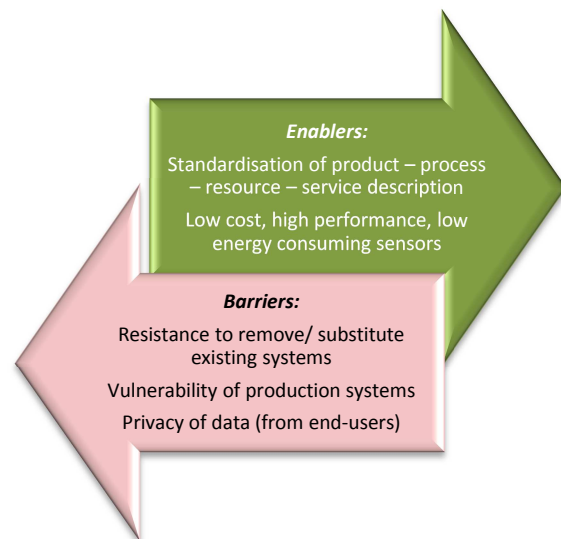
Figure 13: Roadmap for Solution 8: Problem and context-centric display of only crucial information to the users

## 6.9 Engineering Platform for Design/Operations Continuum

This ICT solution involves product and process monitoring and exchanging engineering and usage data throughout the whole product lifecycle. Using a common language, this 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.

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).

**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 has led to some distinct improvements in the usability and energy consumption of its leading products and a clear understanding of how new products need to be designed to be fully recyclable and better serviceable.*



The **implementation challenges** are on 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 new or improved.

The roadmap for this Solution is shown in the figure below.

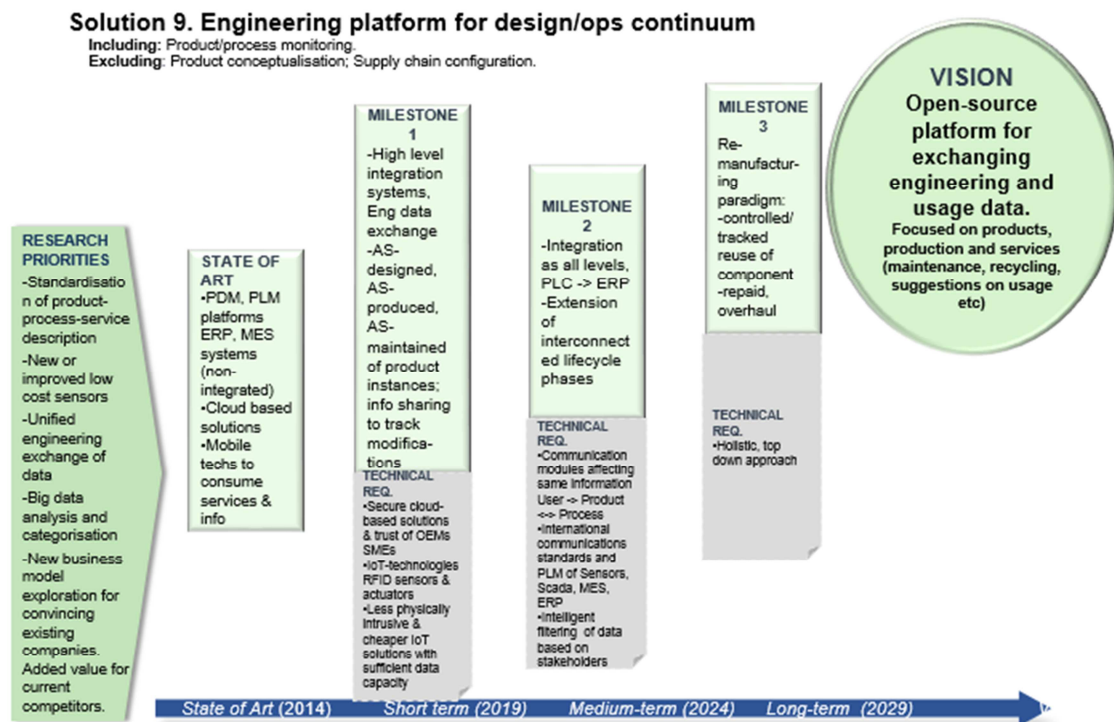


Figure 14: Roadmap for Solution 9: Engineering platform for design/ops continuum

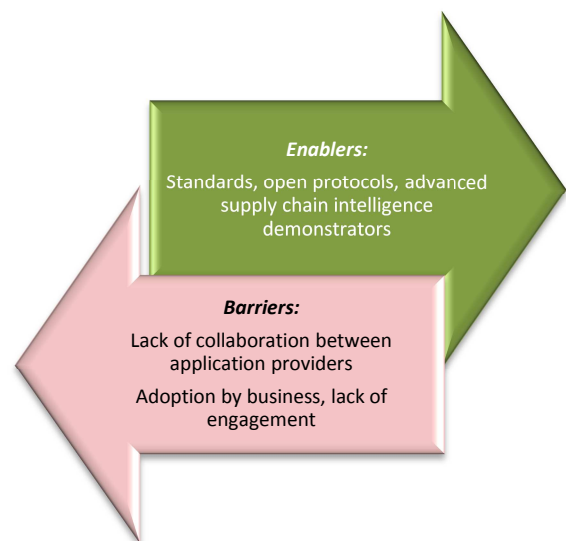


## 6.10 Supply Chain Visibility and Decision Assistance

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.

With this solution internal decisions can be based on information provided by different suppliers in their supply chain taken 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 can be implemented to facilitate decision making.

**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.*



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

The roadmap for this Solution is shown in the figure below.



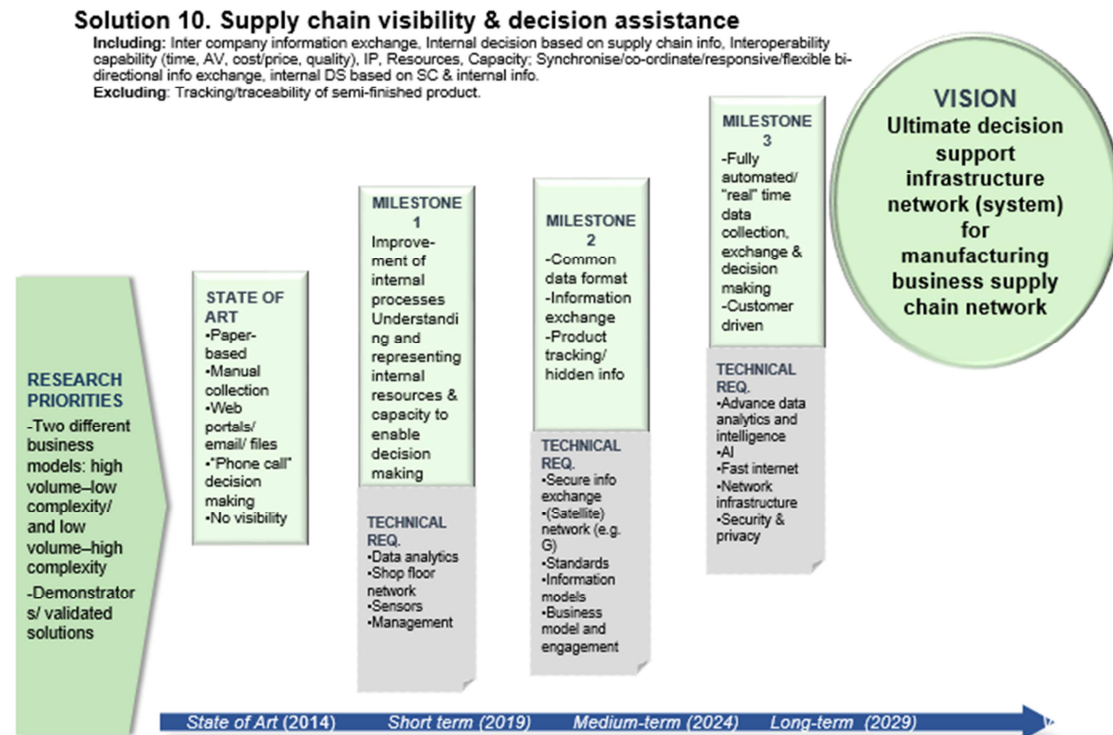
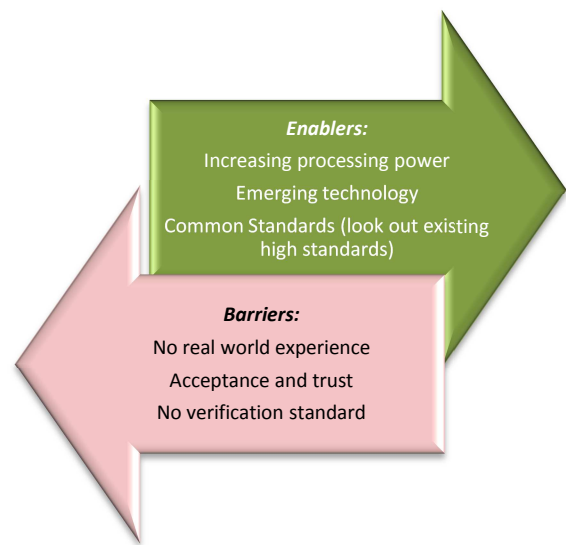


Figure 15: Roadmap for Solution 10: Supply chain visibility & decision assistance

## 6.11 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. 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 can become available in the cloud with full access to all partners in a specific network.

**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.*



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

The roadmap for this Solution is shown in the figure below.

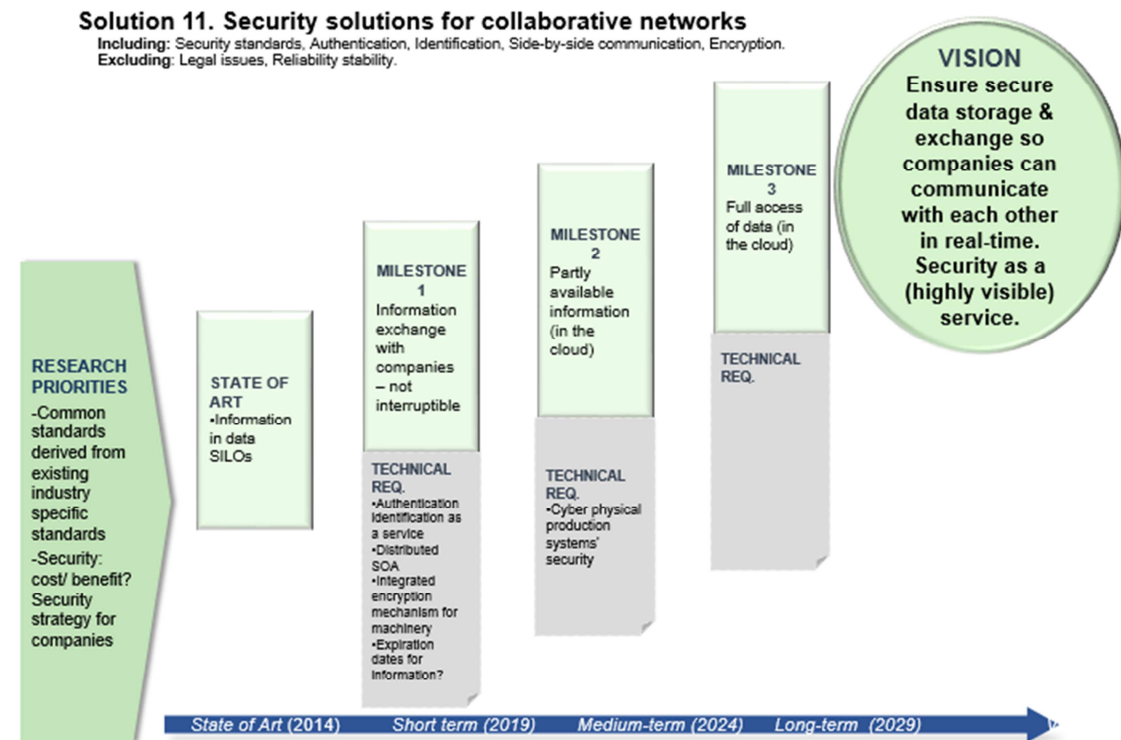


Figure 16: Roadmap for Solution 11: Security solutions for collaborative networks

From the detailed exploration of these 11 ICT solutions specific research recommendations were developed, which are described in the next section. The recommendations are answering three key questions 1) Why they are important and the background, problem, rationale for this recommendation, 2) What is a suitable ICT solution for this problem and 3) How could this ICT solution be implemented.

## 7 Research Recommendations

The following sixteen recommendations were highlighted as the most important to facilitate the adoption and implementation of the eleven ICT solutions. From these sixteen recommendations thirteen are ICT specific, some are enablers for the adoptions and/or implementation of the thirteen ICT recommendations and some are more generic. The detailed recommendations are presented below in no priority order.

## 7.1 Architectures and Services

### 7.1.1 Reference Architectures / Open Architectures

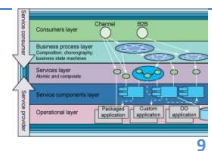
**WHY** – Designing a new ICT system from scratch can be, depending on the project scope, immensely time consuming and costly. Furthermore, in terms of standardisation aspects, reference architectures should be supported to tackle the “wild garden” phenomena. Often there are paradigms, patterns, models and processes, which are similar, if not identical to the ones which can be found in another system. Furthermore when developing, designing and implementing a new ICT system architecture, it is an advantage to integrate best practices for specific parts or processes which are part of the system and ensure it conforms to domain specific standards and interoperability requirements to enable fast and stable implementation.

**WHAT** – The first step to reduce the effort of designing a new ICT system architecture would be to check if a similar, if not identical, system has already been designed and implemented. In that case, the existing system architecture should cover most or all of the basic requirements for the new system. If this architecture is described in an abstract way, which can be transferred and used for other implementations, it can serve as reference architecture, and can be used as a model pattern or a template for the new system with suitable adaptations or extensions. Technical reference architectures can have various levels of abstraction, e.g., high level architectures normally only show different components or function blocks and the relations in a network, while low level architectures describe the communication interfaces by using Application Program Interfaces (APIs) down to the level of the methods. These methods of the APIs’ are being executed in the software of the ICT systems.

**HOW** – Ideally, system reference architectures need to be created by multiple parties to ensure its generality. While selecting appropriate levels of detail for a specific reference architecture, it is essential to consider its purpose. For example reference architecture for the identification of standardisation needs can be quite high-level while one specifying the setup for a specific application might be quite detailed. The result needs to be validated by at least one successful implementation. Even then, reference architecture is normally one of a wide range of possible solutions, which can be improved further. It is therefore important that a reference architecture is an open architecture, which can be further expanded and drawn on by other contributors in the ICT community.

#### Road4FAME recommends:

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



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<sup>9</sup> Image Source: <http://www.ibm.com/developerworks/library/ar-archtemp/>

### 7.1.2 System and Information Integration Architectures

**WHY** – Due to the current increasingly heterogeneous and distributed enterprise applications, different ICT platforms, availability of numerous IT services, smart and mobile devices, sensors, Cyber-Physical Systems and IoT devices it is important that different components can be interconnected or become parts of a “meta-system” at a higher level. While both the diversity in the components’ technology and points of integration increase, users' expectations of coherent, uniform accessibility to data, services and business processes—across applications and access points—are also growing dramatically. However, integration efforts for the interlinkage of systems in order to create higher level applications increase with the complexity of such networked ecosystems.

**WHAT** – In current manufacturing systems, information and data integration effects the flow of data coming from diverse source systems such as operational applications for ERP, CRM, and supply chain, where most enterprise data originates. This is because data has to go through multiple transformations to get it ready for loading into diverse target systems (such as data warehouses, customer data hubs, and product catalogues). Heterogeneity is the norm for both data sources and targets, since these are various types of applications, database brands and file types. All these have different data models, so the data must be transformed in the middle of the process, and these transformations vary widely. In addition, there are the interfaces that connect the system components, which are equally diverse. To manage the complexity of manufacturing IT environments which contain a variety of components and are subject to updating and exchanging processes, ICT architectures are required for system, information and data integration.

**HOW** – Appropriate ICT architectures which are able to represent and handle the complexity and changes in manufacturing IT systems have to be hybrid and combine service-oriented architectures and semantic ontologies in order to enable low-effort integration of interfaces. Similarly to reference architectures, such system and information integration architectures need to rely on architectural patterns and standards to allow simplicity for reuse and consistency. This enables reliable, sustainable and manageable solutions for inter-application and infrastructure integration. At the same time a concise architecture will eliminate, or reduce as much as possible, the brittleness and redundancy inherent in “one-off” point-to-point integrations. System and information integration architectures have to be developed balancing long-range architectural visions and short-term tactical needs. Integration standardisation, reuse and best practices have to be facilitated.

#### Road4FAME recommends:

**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 developed to cope with this challenge.**



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<sup>10</sup> Image Source: <http://www.iebmedia.com/index.php?id=9254&parentid=63&themeid=255&hft=74&showdetail=true&bb=1>

## 7.1.3 Data Capture, Storage and Analysis

**WHY** – Currently the ever faster growing ICT field, especially due to the developments in IoT and CPS areas, is generating more and more data. 90% of all the data available world-wide (by 05/2013) has been generated within 2011-2013; 2.8 zettabytes of data (1 zettabyte = 1 billion gigabytes)<sup>11</sup>. This value is expected to grow almost exponentially reaching around 40 ZB by 2020. But where does this data go? How can it be accessed? How can information be generated from this data? How can it be preserved? And how this information can be used in business models? What are the obstacles and legal implications?

**WHAT** – In regard to the fast developments in the ICT space, Big Data technology has been available for some time past. Big Data is traditionally defined by the 4 “V”s: Volume, Variety, Velocity, and Veracity. Big Data technology encompasses all the technologies which are used to handle very large and very diverse amounts of data in short time, for example NOSQL databases, clustering and cloud-computing. Although the available Big Data technology is very powerful, but it is still not able to process all required data to get the information needed. Currently even the largest, most advanced datacentres are only able to process and store a fraction of the data required. This is why current technologies for capturing, storing and analysing data need to be further improved and adapted to the needs of manufacturing environments, i.e. they have to consider the need for:

- Data mining close to real-time where the analysis results shall be used in-process
- Alignment of semantic content and context of data which is gathered from various manufacturing equipment or related IT systems and for this reason has no or different structures
- Assessment of data quality (e.g. reliability, accuracy) in order to support judgment of the respective analysis results and related actions on the shop floor.

**HOW** – The possible alternatives are either the current computing power to be increased significantly or Big Data technologies to be evolved into Smart Data technologies, which are able to extract only the required and useful data to create equally useful information from it. There should be a balance between how much data and information is collected and used in a sensible manner and what the implications of this data collection are in regard to security and privacy for individuals or IP protection for companies. Additionally, applications need to cope with just-in-time or tardy arriving data/information, due to increased usage of distributed systems and factories, but still being able to perform real-time simulations, update predictions and system control actions.

### Road4FAME recommends:

**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 sensible data and information handling, enabling business models and innovation, while protecting individuals and companies.**



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<sup>11</sup> <http://www.sciencedaily.com/releases/2013/05/130522085217.htm>

<sup>12</sup> Image Source: <http://prismengineering.blogspot.co.uk/>

### 7.1.4 Data and Information Visualisation

**WHY** – Companies use increasingly simulation, visualisation and virtualisation to understand the product and production system behaviour and performance under virtual conditions. Moreover, with the proliferation of the smart devices (e.g. new improved low-cost, miniaturised sensors) for data collection, analysis and visualisation an even greater amount of data of varying quality becomes available for analysis. With the amount of data available constantly increasing current information and visualisation technologies often fail to communicate information in an easily accessible and understandable way. As a result, decision makers often miss important underlying information within the data or are compelled to use a small part of the data only. Finally, there is an increasing need to take data analytics out of the exclusive domain of data specialists. This demand for new technologies and methods to be developed to link data from multiple sources, visualise it and apply predictive analytics.

**WHAT** – Traditionally user interface design considers both the analysis of the context and the specific user needs to achieve a design that supports the major anticipated cases of use. In context aware visualisation more than one design is often supported to tailor different contexts of use. The design becomes more complex as the number of situations increases for example environment, location, identity, activity, and time. New user interface designs need to be able to adapt to situation-dependent user needs. Two other areas of research that can contribute to a better user experience are visual encoding and human centric adaptive interfaces. The first helps people understand data faster while the second deals with the adaptation of input/output modalities to better fit a user's personal needs.

**HOW** – One important research area is context awareness design of innovative user interfaces, for example, precise route planning, and optimal job scheduling and accurate control of the environment in a production environment. Another technological development needs to be on an open data and system integration platform for unstructured data environments that include harmonised/standardised interfaces to enable the progression from dealing with “unstructured” data to self-descriptive to eventually dynamically integrable data sets. Finally, the development of problem and context-centric displays are necessary. These should be able to provide only crucial and personalised information to the users within an organisation with user centric visualisation to support various kinds of employees (e.g. supervisors, operators, product managers, etc.) in problem solving.

#### Road4FAME recommends:

**Visualisation techniques and specifically context-aware responsive visualisation of data which is a major pre-condition for efficient decision support systems. Human-centric adaptive interfaces and context-centric display of only crucial information to enhance usability.**



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<sup>13</sup> Image source: [http://infosthetics.com/archives/2010/11/what\\_is\\_data\\_visualization.html](http://infosthetics.com/archives/2010/11/what_is_data_visualization.html)



### 7.1.5 Security

**WHY** – The advent of the Internet-of-Things (IoT) and Cyber-Physical Production Systems (CPPS) significantly increases the amount of physical and logical devices that are able to communicate autonomously over the manufacturing network. While data from a single device might not raise particular security risks, the same is not true for data captured by multiple devices as these can be organised, inter-related and analysed providing access to potentially sensitive information. Furthermore, some of these devices may have supervision and control responsibilities that influence the outcome of the manufacturing process. Hence, access of these devices by undesired or malicious users can cause malfunctions in critical processes and physical damage. An example of such a risk was demonstrated in a recent experiment by security experts that shown how a simple Wi-Fi light-bulb could leak passwords compromising the whole network (Context 2015).

The manufacturing processes of the future need to be highly flexible and dynamic in order to deliver the customer requirements. This pushes manufacturing companies to have an agile collaboration between partners and suppliers sharing resources and capabilities. This new distributed manufacturing system poses several security challenges such as data theft, leakage of intellectual property and corporate sabotage. The damage of such events to a business is considerable high. For example, according to BCG (Boston Consulting Group 2015), a technology company sustained equipment damage as a result of extensive hacking of its systems. Another company suffered reputation damage after a breach compromised the security of its customers' personal data.

**WHAT** – As more and more network-enabled devices with supervision and control responsibilities are connected, it is crucial to have appropriate security mechanisms to protect the manufacturing businesses. Read and write access to specific manufacturing IT components and equipment has to be managed carefully, and related authentication and authorisation solutions have to be secure and applicable in manufacturing environments

**HOW** – Security protocols for Machine to Machine (M2M) and other forms of communication of manufacturing equipment, related components or network nodes need to be robust. Security solutions for collaborative networks are also required to enable secure data storage and exchange in real-time between different companies. Such security solutions should provide services for authentication, identification and encryption in secure platforms using robust security standards to ensure protection, especially within manufacturing networks, at a reasonable cost. In this relation, research in security strategies for companies would be necessary to ensure balance between security costs and benefits to an organisation. Especially when companies are cooperating and integrating their IT systems, appropriate certification of security standards might help to establish security and trust throughout production networks.

#### Road4FAME recommends:

**Research in security strategy, protocols and tools for companies and standards to protect the networked and distributed manufacturing systems would be necessary to ensure balance between security cost and benefits to an organisation.**



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<sup>14</sup> Image source: <http://internet-safety-2012.info/internet-risks/risks-to-data-security/>

### 7.1.6 Confidentiality

**WHY** – At present and more sophisticated in the near future, the transformation from linear production processes to network centric approaches with specialised and flexible network partners will be more and more omnipresent. These networks will interconnect companies' networks, machines across production plants and supply chains to a higher extent than it exists today. The involvement of consumers and end users in product and service generation processes over the whole value chain will become more important – depending on the domain and the firm this co-creation is already widespread.

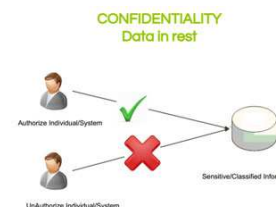
Intellectual Property is one of the most important assets of a company, and within these new networks different levels of information will be shared between different players. This raises concerns about the protection of an individual organisation's intellectual property and confidential information as it flowing through the network.

**WHAT** – Confidentiality concerns will require defining and implementing a set of measures to prevent sensitive information reaching the wrong people while allowing access to people who can and should access it. The tighter integration of organisations within a network increases the number of interfaces and the potential for confidentiality breaches. An external potential intruder could also have access to potentially more weak links to exploit for security attacks. For this reason, it has to be made sure that access to the network is restricted to authorised participants, and that those participants are trustworthy, i.e. that they share IT security mechanisms and intentions. Furthermore, the organisation, implementation and IT-integration of such networks and related IT platforms have to be transparent in order to establish trust.

**HOW** – Due to the fact that in networks interconnected data flows through a larger number of disparate systems there is a shift from a “protecting the perimeter approach” to “protecting the data approach”. Information about who can access the data has to go together with the actual data and have the same meaning throughout the entire network to prevent confidentiality being breached when crossing networks' or systems' boundaries. Appropriate security levels and measures have to be identified for each cross-organisation information flow to keep confidentiality throughout the network thus allowing the establishment of trust.

#### Road4FAME recommends:

**Confidentiality and know-how protection throughout the network of increasingly larger interconnected networks is essential. Therefore technological evolution of authorisation, authentication and encryption mechanisms, as well as the establishment of trust among network participants, to cope with this scenario is recommended.**



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<sup>15</sup> Image source: <http://www.certiology.com/cisco-certifications/ccna/ccna-security/free-ccna-security-study-guide/chapter-1-basic-network-security-concepts-and-techniques.html>

## 7.2 Infrastructures

### 7.2.1 Flexible and Adaptable Manufacturing

**WHY** – Currently, many customers demand for more personalised products that meet their exact requirements in even shorter timescales. This is a true problem for both manufacturers and suppliers as they can hardly manufacture these customised products in volume. This is resulting in more complex and challenging production processes and errors in the supply chain are more likely including a total stop of the manufacturing process. Flexible and adaptable manufacturing can have the following benefits: quicker changes of tools, like dies and stamping machineries, reducing downtime and allowing a more efficient use of tools and machinery in total. Furthermore, this advanced manufacturing method results in an increasing production capacity and flexibility as well as a reduction of labour and waste.

**WHAT** – Flexibility and adaptability can allow a manufacturing chain to react fast to changes, whether predicted or unpredicted. Processes would adapt themselves in order to manufacture products which fully comply with the customer requirements. On the other hand, an error in the chain would not stop the manufacturing process because it would be able to solve the problem by enquiring and adapting to the specific circumstances that caused the issue, or give notice to solve the problem quicker.

**HOW** – Flexible and adaptable manufacturing is possible by monitoring all manufacturing processes and implementing new networking protocols and mechanisms for linking together the different equipment in the manufacturing processes. Standardisation is key in this approach to facilitate interoperability and vertical integration of smart components. It is also necessary to model processes to facilitate real-time monitoring and control of the shop floor and the entire supply chain. These models will also need to be context-aware, account for human-interaction and include self-learning mechanisms. Usually machines, mainly for cost reasons, are designed and built with a single process/product in mind, allowing little flexibility, especially in terms of hardware compatibility (i.e. capability of working with products of different sizes, shapes or handling needs). For future manufacturing it is essential that those hardware barriers are minimised to enable the use of machines on a wide range of products through configuration (plug-and-produce).

#### Road4FAME recommends:

**Self-adapting, resilient and reconfigurable manufacturing environments need to be facilitated by standardisation of intra- and inter-machine communication. Wireless technologies, context awareness, human-interaction and self-learning (e.g. for production configuration) mechanisms, etc. can significantly contribute to efficiency improvements of the (re-) configuration, ramp-up, and optimisation of manufacturing environments.**



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<sup>16</sup> Image source: <http://www.nsf.gov/pubs/2000/nsf00137/nsf00137l.htm>

## 7.2.2 New or Improved Low-cost, Miniaturised Smart Sensors

**WHY** – Current developments in the area of Internet of Things have indicated the potential that can be enabled by IP-connected devices which are capable to communicate over the internet. The do-it-yourself communities are sprawling with net innovative projects and products, which use IoT technology and all kinds of imaginable sensors. This sensor technology is also the foundation for Cyber-Physical Systems. But many concepts for CPS, especially for industrial applications, are still in development because the available technology is not just sufficiently advanced and (economically) scalable.

**WHAT** – Current available sensors still need to be improved in regards of interfaces and integration capabilities. Often sensors need to be adapted manually, drivers and libraries for data manipulation often have to be modified or ported manually for a specific application which makes the integration, implementation and use of sensors in smart devices quite complicated. Intelligent sensors need to be able to communicate their own capabilities and self-descriptions to the connected applications and devices by themselves. Currently commercially available modular solutions which are much easier to use, are too expensive and not flexible enough, because they are bound to predefined form factors. Also (internet) connectivity of sensors often relies on gateway devices, which are either based on BLE (Bluetooth low energy) or other, partly proprietary protocols. Only very few sensors are directly IP capable over Wi-Fi, although Wi-Fi or other wireless technologies are currently not sufficiently energy efficient and need extensive maintenance to remain operational over long periods of time.

**HOW** – The sensor hardware needs to be further improved. Sensors need to become more energy efficient, while being able to stay connected wirelessly. For this, standards for interoperability need to be improved and implemented, so that the integration and application of sensors becomes easy and efficient. In addition, smart sensors should be able to provide their self-description to be directly usable as Cyber-Physical Systems of systems. They need to have built in computational power that enables pre-processing and aggregation of data and information, to prevent information overload, as transferring large amounts of information into the cloud for processing will at some point become inefficient. Due to the increasing demand for sensors in the last few years, production capacities have been increased which led to price reductions, but for sensors to be ubiquitous and enable new applications the price has to be reduced even further.

### Road4FAME recommends:

**Sensors need to become cheaper, smarter, smaller and more energy efficient, to enable new applications that until now were not possible or viable enough due to technological and economic restraints.**



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<sup>17</sup> Image source: [http://www.sensorsportal.com/HTML/DIGEST/september\\_07/Smart\\_sensor.htm](http://www.sensorsportal.com/HTML/DIGEST/september_07/Smart_sensor.htm)

### 7.2.3 CPPS - Cyber-Physical Production Systems

**WHY** – The increasing complexity of production today is being caused partially by the demand for more product variety in smaller lot sizes. To be able to handle this complexity and maintain efficiency at the same time, new technologies need to be developed or adapted and implemented in manufacturing environments.

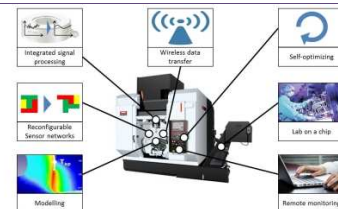
**WHAT** – New and improved production systems, which are able to provide quick reconfiguration of production processes, even automated on-the-fly reconfiguration, are a possible and feasible solution to handle this complexity. Thus it is possible to prevent idle time which is being currently caused by lengthy manual reconfiguration of production equipment. Such production systems need to be aware about their hardware and software components, and provide their capabilities to the overall manufacturing environment in the form of services in order to enable flexible integration.

**HOW** – One of the most promising approaches is the use of Cyber-Physical Systems CPS, or in the case of production environments, Cyber-Physical Production Systems (CPPS). A CPPS is able to provide autonomously its self-description, a unique identification and is securely connected via global open networks (e.g. the internet) to other equipment and IT systems. With this functionality it can be interconnected with production IT systems and services, which are able to provide it with job data, even remotely from cloud based platforms and services.

Appropriate CPPS self-descriptions, service interfaces, and infrastructures which enable their flexible orchestration and integration have to be developed in order to push forward the widespread roll-out of CPPS in manufacturing ecosystems.

#### Road4FAME recommends:

**CP(P)S concepts need to be further evaluated and implemented. Certain standards such as self-description, integration/interface, intercommunication and orchestration need to be developed for on platform and system level.**



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<sup>18</sup> Image source: [http://www.awk-aachen.de/\\_C1257B97002C1799.nsf/html/en\\_03d85b267197e859c1257c7300418c6b.html](http://www.awk-aachen.de/_C1257B97002C1799.nsf/html/en_03d85b267197e859c1257c7300418c6b.html)

### 7.3 Other

#### 7.3.1 New Algorithms

**WHY** – Data processing has become very important. Collecting data and information is not sufficient anymore unless these can be converted to knowledge. The large amount of information available requires new algorithms to process and calculate data in real-time, which flows from the different sensors in machines and tools in a production environment. Timely analysis of this information can enable the improvement of manufacturing processes, accelerate manufacturing processes, reduce production time, and increase resource efficiency. New types of algorithms for distributed processing of data and systems in close-to-real time would be necessary in order to make them applicable for production, and other intra-factory control system layers.

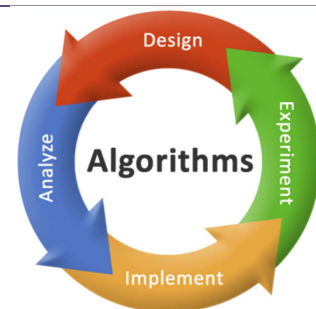
Finally, the ever increasing global distribution of resources and collaboration of enterprises in networks will require new algorithms and technologies for optimal enterprise configuration. New algorithms will also be required to facilitate the enterprise and network reconfiguration and adaptation to market dynamics and changing needs.

**WHAT** – Future research should focus on the development of new algorithms for data conveying, filtering, fusing and data analysis for effective decision making. Algorithms and methodologies for problem solving in collaborative systems that incorporate human-machine interfaces will be also required, as well as the development of algorithms for multiple organisations reconfiguration (dynamic networks) and adaptation and for production/process optimisation.

**HOW** – The inclusion of new algorithms needs to be coupled with the implementation of sensors for data collection to monitor, analyse, manage and adapt the manufacturing processes (mainly machinery and production environment). Central processing units should be also included in the manufacturing environment to facilitate data collection and analysis.

#### Road4FAME recommends:

The development of easy to use algorithms for analysis, and real-time prediction needs to both address various manufacturing enterprises and also be time and resource efficient and cost effective, especially for SMEs. It also has to incorporate knowledge from other domains, where necessary. Furthermore, the algorithms should be able to be executed in a distributed manner to ensure their applicability in manufacturing environments.



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<sup>19</sup> Image source: <http://openclassroom.stanford.edu/MainFolder/CoursePage.php?course=IntroToAlgorithms>

### 7.3.2 Modelling

**WHY** – The new challenges in manufacturing require synchronisation of the digital-virtual factory and the use of modelling and simulation for decision support. The increasing manufacturing complexity especially in technologically advanced sectors such as electronics, avionics and automotive requires new digital models that are triggered by smart objects, processes and enterprise scenarios.

There is also the need of improved models to optimise sustainable manufacturing, product servitisation and design integration of product services. This is important for predicting manufacturing systems behaviour, testing innovative concepts and validating products and processes, ultimately saving time, saving money, and resources.

**WHAT** – Modelling consist of creating digital representations that describe a real manufacturing process or environment. Models can ideally synthesise all aspects of a manufacturing enterprise (equipment, processes, and people that interact with manufacturing systems) for understanding high-level dynamics of complex manufacturing systems. Modelling and simulation technologies can facilitate decision making for optimisation reconfiguration networks. They can also enable the creation of virtual prototypes in manufacturing processes and systems.

**HOW** – Modelling precedes production and includes both product lifecycle design and factory lifecycle design before the production process begins.

Developing smarter and better models that are able to provide not only details of design but also have greater predictive capacity can help reduce physical prototyping needs or construction of pilot plants. These modelling processes should include properties of materials and components as well as their variations, and for example help identify and mitigate the effects of corrosion, temperature or stress on produced components.

#### Road4FAME recommends:

The development of smarter and better information and domain models can provide not only design details but also greater predictive capacity in order to reduce physical prototyping needs or construction of pilot plants. Simulations, virtual reality, tacit knowledge modelling and User eXperience (UX) of mathematical modelling potentially supports problem solving, decision support and rapid prototyping.



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<sup>20</sup> Image source: [http://www.igcseict.info/theory/7\\_1/model/](http://www.igcseict.info/theory/7_1/model/)



### 7.4 ICT Enablers

#### 7.4.1 Interoperability and Standards

**WHY** – Nowadays, technologies that help users access globalised networks and connect various devices together are developing fast. As new developments in devices, systems, equipment, software applications, services and platforms are rapidly increasing these components are expected to work seamlessly together. But there are specific requirements which have to be considered; everything has to be as effortless, reliable, secure, safe, and cost-effective, while at the same time being versatile, flexible and efficient. So, how does one system know how to communicate with another system? How does it even know what kind of system it is trying to communicate with? How can someone who is tasked to interconnect several different components or devices know how to do it “the right way”?

**WHAT** – Complex ICT systems and other components must be able to communicate and work together throughout all levels and across enterprise boundaries. This ability is called interoperability and it needs to be designed and built into the components from the start. Interoperability is a crucial factor in the success of modern technologies, and it is the market demand which has ensured that interoperability holds a prominent position in standardisation. Standardisation helps to prevent a wild garden of technologies which are not compatible. One of the key motives for the development of ICT standards is to facilitate interoperability between products in a multi-vendor, multi-network and multi-service environment.

**HOW** – To provide a solid foundation upon which new technologies can be developed and existing practices can be enhanced it is necessary to set standards. The application of standardised product-process-service descriptions and their alignment across the value chain is recommended in order to enable seamless integration and management of production processes throughout production networks, as well as seamless system integration and information exchange throughout the whole product lifecycle. Furthermore, integration standards are needed throughout all manufacturing IT layers – from sensors to business analytics. Initially, existing standards need to be screened and evaluated if they can be adopted. New standards should only be designed, proposed or implemented if absolutely necessary. If a standard is not adequate but could be extended, this extension should be proposed to the responsible standards committee. In this way, standards especially for interoperability, can open up market access, provide economies of scale, encourage innovation and increase awareness of technical developments and initiatives.

#### **Road4FAME recommends:**

**Existing standards need to be examined and adopted if possible.**

**Contributions to improve a particular standard are encouraged.**

**Standards for interoperability will become even more important for platforms, products and services of the future.**



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<sup>21</sup> Image source: <http://www.apec.org/Groups/SOM-Steering-Committee-on-Economic-and-Technical-Cooperation/Working-Groups/Telecommunications-and-Information.aspx>

### 7.4.2 Establishment of Demonstrators

**WHY** – Many manufacturers tend to be conservative and prefer established ICT solutions instead of innovative and potentially risky new approaches. Reliable processes and systems are one essential condition in mechanical and process engineering. ICT solutions are sometimes associated with down time caused by a server crash or server failure for example. Decision-makers of OEMs or suppliers fear loss of production and therefore tend to avoid decisions that foster the development of unconventional or untested products or solutions. The step towards a CPS-based solution is considered a radical disruption by many manufacturers and it will require extensive testing to be accepted and eventually adopted by industry.

**WHAT** – New radical ideas need to demonstrate tangible benefits over established solutions in order to be adopted. The objective of demonstrators and pilots is to validate the feasibility of a new or upgraded solution, product or service. Working demonstrators and pilots are one of the most effective ways to show and convince a broad range of sceptical decision-makers. Innovations sprawl from an innovative company or institution to the adopters after a certain time – demonstrators are a helpful way to accelerate this development. This kind of best practice displays the practical application of technologies and further promotes the development of the technology in an operational or nearly operational environment.

**HOW** – Due to high investment costs companies, especially SMEs, hesitate implementing demonstrators and pilots by themselves. Instead they often opt to share the risk within a network of firms. The European Commission should support demonstrator and pilot initiatives by giving advice and funding to reduce the risk for individual companies or networks in order to increase the possibility of success. The establishment of pilots and demonstrators in a real setting will demonstrate the chances of a new technology. Although, some companies are only interested in one section of the value chain, demonstrators should engage the entire value-added chain in order to show a gapless feasibility of the innovative technology. A pilot is important to show, not only the technological conversion, but also the business opportunities, which are possible after a successful demonstration. A result of a successful demonstrator program would be the adoption of a greater range and variety of Cyber-Physical Systems and a larger impact in the development of a CPS-based manufacturing industry.

#### Road4FAME recommends:

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



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<sup>22</sup> Image source: <https://www.epsrc.ac.uk/newsevents/news/indiaukict/>

### 7.5 Other Enablers

#### 7.5.1 Incorporation of Psychology into ICT Research

**WHY** – It has been shown that the incorporation of human factors and ergonomic aspects improve the efficiency of ICT systems as well as positive work experience. For this reason, manufacturing companies often foster research activities concerning human factors in order to optimise their ICT systems by their workforce. The incorporation of psychological aspects into ICT research supports manufacturing firms in the long run to improve worker safety, efficiency and satisfaction. In addition, this results in the development of new products with better usability and supports to analyse human behaviour for decisions taking. New advances in computational technologies have focused mainly on tool building neglecting psychological aspects. Joint cognitive decision support systems require mainly computational technology support that helps the user in the process of reaching a decision, and not simply make or recommend solutions.

**WHAT** – Human factors psychology is used in different topics, including ergonomics, cognitive decision support systems, workplace safety, workplace adaption/personalisation, human capability, product design and human-machine interaction. Future research should try to understand the influence of human psychology and social sciences on the decision-making process. Decision support systems should take the context awareness and the user specific aspects into consideration. The information, which is analysed and reported to the users, should include the specific human skills and user profiles. Human-machine interfaces should be adaptable to each user status and each specific situation in order to support individuals by making business decision procedures easier or to enable the system deriving a decision when it is designed with artificial intelligence.

**HOW** – New models, data and techniques are needed to help designers build effective interactions between human and machine elements in manufacturing systems; these systems should include cognitive technologies for user status monitoring and analysis. Human-machine interaction should take into account the instructional message design, graphic design, and usability. Development of human behaviour and cognitive aspects in human decision-making processes should also be encouraged as complementary to the ICT technologies.

#### **Road4FAME recommends:**

**Incorporation of psychology into ICT research is fundamental in order to develop joint cognitive decision support systems. For this intense human-machine collaboration is essential. This would only be possible by incorporating psychology into ICT research in order to get a more effective human-machine interaction.**



<sup>23</sup> Image source: <http://blogs.bournemouth.ac.uk/research/2012/02/15/fp7-ict-ambient-assisted-living-call-pre-announcement-and-info-day/>

## 7.5.2 Applied, Multidisciplinary Research with Large Scale Industrial Collaboration

**WHY** – As manufacturing is becoming nowadays, especially regarding stronger involvement of IT, an interdisciplinary domain involving a huge variety of stakeholders, machineries, processes and systems, research in manufacturing should be encouraged to follow a multidisciplinary approach involving many different scientific branches. Many manufacturing firms are involved in supply networks where collaboration is critical to success. However, in terms of research an approach that aims at more applied and multidisciplinary aspects including a variety of companies would result in the following positive aspects:

- Finding new opportunities new sectors or markets
- Doing or having access to advanced research
- Enhancing efficiency
- Reducing costs
- Amplifying the impact of a particular solution
- Addressing greater challenges that are difficult to tackle alone
- Leveraging own resources and accessing skills and knowledge not available in-house

**WHAT** – Within large-scale industrial collaborations supported by applied, multidisciplinary research the knowledge, skills or facilities of the collaborating firms should be complementary and provide benefit for each stakeholder and the collaboration in total. It is not uncommon to find a big facility with the newest equipment, but lacking of expertise in a particular required technology field. In these cases collaborative effort between big industrial entities, academia, and services providers is fundamental to address the new challenges which are emerging in the manufacturing sector.

**HOW** – Already existing calls for collaborative projects are launched at the European, national and local levels and need to be extended to further calls supporting applied and multidisciplinary research with large-scale industrial collaborations. These usually co-funded calls need to be accompanied by further private initiatives and clusters which promote collaborative work between entities working in the same or complementary sectors.

### Road4FAME recommends:

**Collaborative networks which can provide the necessary power through aggregation of knowledge and resources, can achieve far more than any individual firm. Different organisations with different profiles work together by bringing their acquired knowledge, their expertise and their infrastructure in order to create, develop or implement new ideas.**



### 7.5.3 Supporting Education in the Field of CPS

**WHY** – Cyber-Physical Systems combine information and communication technologies with engineering disciplines resulting in a higher grade of complexity. In addition, the trend towards less hierarchical and more decentralised organisation structures within companies leads to more responsibility for individual employees. This trend coupled with the demographic change in Europe such as population reduction or an increase of the number of older employees in certain European areas require an adaption of education and training content and methods. An emerging domain like CPS implies insecurity and disruption, which needs a labour force that is more technologically savvy and mobile than before.

**WHAT** – These challenges require that employees in companies, service firms (e.g. insurance, law) and government policy have specialised CPS knowledge. To achieve this level of labour force training, the education at all levels (e.g. school, university, professional) needs to be adapted to develop a workforce with both specialised CPS know-how as well as interdisciplinary skills. Awareness building from management to shop floor level is a first important step to get both the decision-makers and the employees on the right path of CPS. Low-skilled workers need to be up-skilled to enable them to review, maintain and analyse data. The share of ‘traditional’ engineers is expected to gradually decrease and more process engineers with relevant IT skills will be required in the future for the successful implementation of a CPS-based economic system. This transition could also be supported by computer scientists with manufacturing knowledge. It is essential that industry and academia work together to develop the required skills necessary for the industrial sector.

**HOW** – Universities and further education institutions need to incorporate the new discipline of CPS in their curriculums to fulfil the above mentioned demands. As well as training a ‘new generation’ of engineers, life-long learning, hands-on and best practice transfer to working engineers and job-related learning of the labour force should be encouraged together with better knowledge management within companies. In this context digital learning techniques and e-learning may become more important due to its flexibility and easy updatability. Engineering and computer science faculties should work together in order to create cross-disciplinary study programs for both engineers and information scientists. This cross-fertilisation is essential for building awareness for the topic CPS in both disciplines. Certificates as well as degrees in the field of CPS need to be standardised in order to increase its acceptance and practice.

#### **Road4FAME recommends:**

**Education should move to the forefront of CPS to guarantee the development of 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 one important step to secure the competitive position of the European economy.**



## 8 Business Strategies for Industry

### 8.1 Business Models and Opportunities

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

- Ownership is likely to become more and more decoupled from the 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/regulations. A key example of this is green/sustainable manufacturing which is driving 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.

### 8.2 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 to many SMEs from offering services is the risk of liability introduced from 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.



## 9 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 enable a critical mass 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 fund 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 digitalisation 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. 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.

## 10 Conclusions

A roadmap for ICT in manufacturing was produced through literature research, expert panel meetings, interviews, and five one-day workshops involving over 80 participants from Europe. The participants validated the information already gathered from desk research and initial interviews, added further content to the roadmap, prioritised the content on importance, opportunity for adding value and feasibility and helped highlight the research required for further ICT development and implementation in manufacturing.

The following eleven ICT manufacturing solutions were considered important for the sector:

### ICT Solutions

#### For facilitating shop floor production

- **Big data analysis and use for quality control:** A solution to develop big data analytics for production to enable full transparency on the shop floor.
- **Flexible production equipment and interconnections:** A solution that enables different types of products to be produced at the same time inside a production plant. It 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:** This is a Decision Support System (DSS), based on multiple criteria that combine machine and human expertise.
- **Engineering Platform for design/operations continuum:** This ICT solution involves product and process monitoring and exchanging engineering and usage data throughout the whole product lifecycle from production stage to its end of life.

#### For enhancing inter-company activities especially with its customers

- **Customer and demand data gathering for analysis:** A solution that ensures that a product always meets the customer requirements and provides them with exactly what they want.
- **Product and service co-design with customer:** This is a forward looking range of ICT solutions in line with current socio-technological trends in manufacturing that foresee an 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:** 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.
- **Security solutions for collaborative networks:** This ICT solution enables secure data storage and exchange in real-time between different companies. It should provide services for authentication, identification and encryption in secure platforms using robust security standards.

### Other ICT solutions applicable throughout the value chain

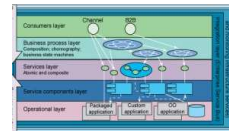
- **Open data and system integration platform for unstructured data environment - including harmonised/standardised interfaces:** This solution is required to enable the progression from dealing with “unstructured” data to self-descriptive to eventually dynamically integrable data sets.
- **Information technology (IT) and operational technology (OT) convergence: integrated architecture of Product Lifecycle Management-Manufacturing Execution Systems-Enterprise Resource Management (PLM-MES-ERP):** The desired vision for this solution is to enable the 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:** This solution provides personalised information and user centric visualisation within an organisation to aid a range of employees (e.g. supervisors, operators, product managers, etc.) in problem solving.

Overall **sixteen research recommendations** were put forward. These were considered necessary for realising the ICT manufacturing solutions, and significantly enhancing the capability of current manufacturing environments. These are summarised below:

### Recommendations for ICT Architectures and Services

#### Reference architectures / open architectures

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



#### System and 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 developed 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 sensible 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 which is a major pre-condition for efficient decision support systems. Human-centric adaptive interfaces and context-centric display of only crucial information to enhance usability.



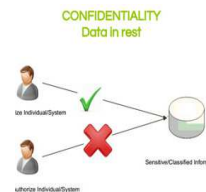
### Security

Research in security strategy, protocols and tools for companies and standards to protect the networked and distributed manufacturing systems would be necessary to ensure balance between security cost and benefits to an organisation.



### Confidentiality

Confidentiality and know-how protection throughout the network of increasingly larger interconnected networks is essential. Therefore technological evolution of authorisation, authentication and encryption mechanisms, as well as the establishment of trust among network participants, to cope with this scenario, is recommended.



## Recommendations for ICT Infrastructures

### Flexible and adaptable manufacturing

Self-adapting, resilient and reconfigurable manufacturing environments need to be facilitated by standardisation of intra- and inter-machine communication. Wireless technologies, context awareness, human-interaction and self-learning (e.g. for production configuration) mechanisms, etc., can significantly contribute to efficiency improvements of the (re-) configuration, ramp-up, and optimisation of manufacturing environments.



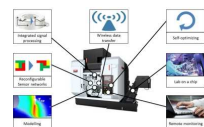
### New or improved low-cost, miniaturised smart sensors

Sensors need to become cheaper, smarter, smaller and more energy efficient, to enable new applications that until now were not possible or viable enough due to technological and economic restraints.



### CPPS - Cyber-Physical Production Systems

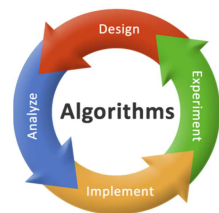
CP(P)S concepts need to be further evaluated and implemented. Certain standards such as self-description, integration/interface, intercommunication and orchestration need to be developed for on platform and system level.



## Other Technology Recommendations

### New algorithms

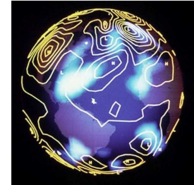
The development of easy to use algorithms for analysis, and real-time prediction needs both, to address various manufacturing enterprises and also be time and resource efficient and cost effective, especially for SMEs. It also has to incorporate knowledge from other domains, where necessary. Furthermore, the algorithms should be able to be executed in a distributed manner to ensure their applicability in manufacturing environments.





### Modelling

The development of smarter and better information and domain models can provide not only design details but also greater predictive capacity in order to reduce physical prototyping needs or construction of pilot plants. Simulations, virtual reality, tacit knowledge modelling and User eXperience (UX) of mathematical modelling potentially supports problem solving, decision support and rapid prototyping.



### ICT Enablers Required

#### Interoperability and standards

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



#### Establishment of demonstrators

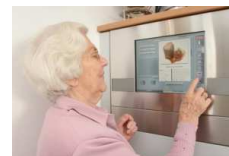
Demonstrators need to be promoted and supported in order to show the feasibility and opportunities of new ICT technologies and solutions. This is a way to demonstrate the technological and economic opportunities especially for SMEs.



### Other Enablers

#### Incorporation of psychology into ICT research

Incorporation of psychology into ICT research is fundamental in order to develop joint cognitive decision support systems. For this intense human-machine collaboration is essential. This would only be possible by incorporating psychology into ICT research in order to get a more effective human-machine interaction.



### Applied, multidisciplinary research with large scale industrial collaboration

Collaborative networks which can provide the necessary power through aggregation of knowledge and resources, can achieve far more than any individual firm. Different organisations with different profiles work together by bringing their acquired knowledge, their expertise and their infrastructure in order to create, develop or implement new ideas.



#### Supporting education in the field of CPS

Education should move to the forefront of CPS to guarantee the development of 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 one important step to secure the competitive position of the European economy.





These sixteen recommendations are expected to tackle a few long-standing **challenges in manufacturing**, which impact particularly upon small and medium-sized enterprises (SME), such as:

- increasing demands from customers for flexibility, customisation and track-and-trace capability
- a highly heterogeneous manufacturing ICT landscape and lack of interoperability
- high implementation costs on ICT solutions
- Cybersecurity

## Business Needs and Driving Innovation

There are already many initiatives for driving innovation. These include:

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

All these play an important role in technology transfer. They bring stakeholders and the value chain together, develop critical mass in specific sectors and technologies, provide strategic vision and competitive advantage in key technologies, and accelerate the uptake and acceptance of technologies by large and small companies through demonstration in real world scenarios.

It is recommended that European Commission funding is used to foster linkage between these fragmented initiatives to create a European critical mass in digital manufacturing and transfer technology 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 engage interest and commitment by large companies to work together and develop supporting ecosystems of SMEs and mid-sized companies.

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 also 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 in digital manufacturing. In the near future, the workforce will need a different skill set and it will be required to be more adaptive to cope with the pace of ICT technology change. Education is also needed to raise awareness from the management to the factory floor of societal issues such as sustainability and 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 therefore 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.

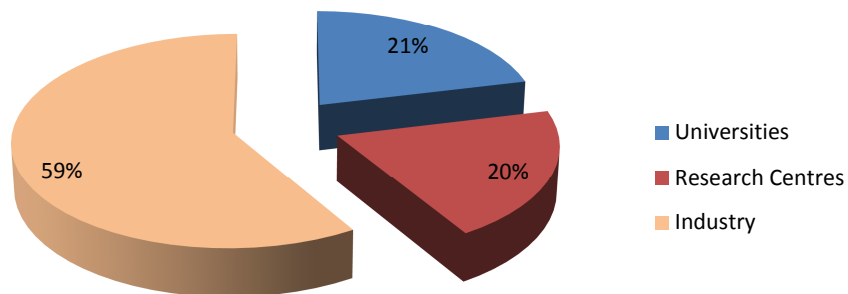
## 11 Appendix 1: List of contributors to the roadmap

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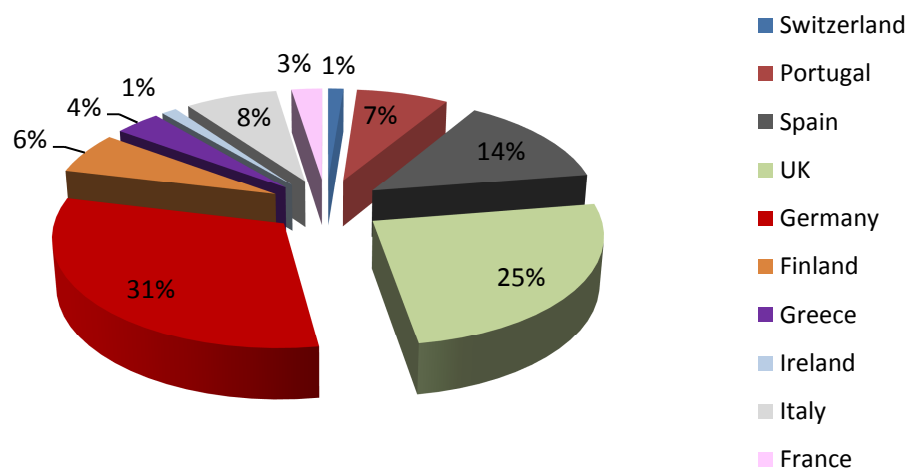
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### Participation per type of organisation



### Participation per EU Country



## 12 Appendix 2: Links of ICT Solutions to Manufacturing Needs, Technologies and Recommendations

ICT Solution 1: Open data and system integration platform			
Manufacturing Trend or Need			
Monitoring and Decision Making for Performance Optimisation	Flexible manufacturing	Cost reductions by improvements in business processes and in particular production processes	Integration of human worker in manufacturing process
<ul style="list-style-type: none"><li>Increasing complexity of products, processes, and supply networks</li></ul>	<ul style="list-style-type: none"><li>Demand by customers for individualised/highly configurable products</li><li>Identify/anticipate changes in demand</li></ul>	<ul style="list-style-type: none"><li>Shorter product lifecycles;</li><li>Reduction of lead times to produce and deliver a product;</li><li>Reduction of start-up times, fast scale-up of production</li></ul>	<ul style="list-style-type: none"><li>Increasing hybrid cross-over products/embedded IT and integrated services</li></ul>
Links between ‘Required Research and Technology’ and ‘Research recommendations’			
Required Research and Technology		Research recommendations	
Improved usability: hide complexity from users; multi-modal user interfaces; User-centred design; context-aware user interfaces; user-specific adaption; context-aware user interfaces		Reference/Open Architectures System and Information Integration Architectures	
Make complexity manageable			
Manufacturing IT as a Service: Exploit Cloud Technologies; Cloud manufacturing/service-oriented manufacturing			
Develop a core infrastructure and training materials for such a platform		System and Information Integration Architectures	
Big Data: Data analysis/Data fusion; Prediction/Forecasting and decision making (e.g. for factory optimisation) - local or global; Research around data quality, tools and methodologies for generating, distributing and verifying consistent datasets within a manufacturing environment		Data Capture, Storage and Analysis	
Security: Operational safety and reliability;		Security	
Privacy and know-how protection; Establishment of trust		Confidentiality	
Total customisation/ad-hoc establishment of production settings		Flexible and Adaptable Manufacturing	
(Coordination of) Autonomous manufacturing system components			
Horizontal integration and optimisation of value chains			
Intelligent components/Internet of Things (throughout the supply chain);		New or Improved low-cost, miniaturised smart sensors	
Intelligent self-powered wireless sensors to allow M2M communications, gather process data, KPIs etc.		CPPS-Cyber-Physical Production Systems	

Factory knowledge base: virtual representation of manufacturing environments; Data consistency by means of (standardised) semantic models/system descriptions;	Modelling
Knowledge transfer between manufacturing and engineering	Establishing of Demonstrators
Human-centric digital age - Knowledge about human behaviour using digital media etc.	Incorporation of psychology into ICT research
Stakeholder education (users, decision makers etc.);	Supporting Education in the field of CPS

ICT Solution 2: Customer and demand data gathering and analysis			
Manufacturing Trend or Need			
	Flexible manufacturing	Cost reductions by improvements in business processes and in particular production processes:	
	<ul style="list-style-type: none"> <li>Demand by customers for individualised/highly configurable products</li> </ul>	<ul style="list-style-type: none"> <li>Shorter product lifecycles;</li> <li>Reduction of lead times to produce and deliver a product</li> </ul>	
Links between 'Required Research and Technology' and 'Research recommendations'			
Required Research and Technology		Research recommendations	
Improved usability: hide complexity from users; make complexity manageable; multi-modal user interfaces; User-centred design		System and Information Integration Architectures Reference/Open Architectures	
Make complexity manageable		System and Information Integration Architectures Reference/Open Architectures	
Big Data: Data analysis/Data fusion/data mining; Prediction/Forecasting and decision making (e.g. for factory optimisation) - local or global		Data Capture, Storage and Analysis	
Security: Operational safety and reliability;		Security	
Privacy and know-how protection; Establishment of trust		Confidentiality	
Intelligent components/Internet of Things (throughout the supply chain);		New or Improved low-cost, miniaturised smart sensors	
Intelligent self-powered wireless sensors to allow M2M communications, gather process data, KPIs etc.		CPPS-Cyber-Physical Production Systems	



ICT Solution 3: IT-OT convergence: integrated architecture PLM-MES-ERP			
Manufacturing Trend or Need			
Monitoring and Decision Making for Performance Optimisation	Flexible manufacturing and Supply Chain Flexibility	Cost reductions by improvements in business processes and in particular production processes:	Integration of human worker in manufacturing process
<ul style="list-style-type: none"><li>Increasing complexity of products, processes, and supply networks;</li></ul>	<ul style="list-style-type: none"><li>Demand by customers for individualised/highly configurable products;</li><li>Virtualisation and digitisation;</li><li>Increasing flexibility of production environments;</li><li>Flexibility in supply chain participation</li></ul>	<ul style="list-style-type: none"><li>Shorter product lifecycles;</li><li>Reduction of lead times to produce and deliver a product;</li><li>Reduction of start-up times, fast scale-up of production</li></ul>	<ul style="list-style-type: none"><li>Shortage of skilled staff;</li><li>Extension of ICT perspective to production site/company associations</li></ul>
Links between ‘Required Research and Technology’ and ‘Research recommendations’			
Required Research and Technology		Research recommendations	
Manufacturing IT as a Service: Exploit Cloud Technologies; Development of cloud computing resilience		Reference/Open Architectures	
Cloud manufacturing/service-oriented manufacturing			
Web 2.0 connectivity vs. data exchange tools (to allow collaborative virtual enterprises to work together efficiently)		Reference/Open Architectures System and Information Integration Architectures	
Complexity management		System and Information Integration Architectures	
Security: Operational safety and reliability;		Security	
Privacy and know-how protection; Establishment of trust		Confidentiality	
Horizontal integration and optimisation of value chains		Flexible and Adaptable Manufacturing	
Managing manufacturing uncertainty in an increasingly complex value chain			
Real-time monitoring; Real-time capabilities		New Algorithms	
Factory knowledge base: virtual representation of manufacturing environments; Data consistency by means of (standardised) semantic models/system descriptions;		Modelling	
Development of interoperability and standards		Interoperability and standards	
Knowledge transfer between manufacturing and engineering		Establishing of Demonstrators	
Human-centric digital age - Knowledge about human behaviour using digital media etc.		Incorporation of psychology into ICT research	
Stakeholder education (users, decision makers etc.);		Supporting Education in the field of CPS	

ICT Solution 4: Product and service co-design with customer			
Manufacturing Trend or Need			
	Flexible manufacturing	Cost reductions by improvements in business processes and in particular production processes	Integration of human worker in manufacturing process
	<ul style="list-style-type: none"><li>• Demand by customers for individualised/highly configurable products;</li><li>• Urban production;</li><li>• Additive manufacturing/3D-printing;</li><li>• Virtualisation and digitisation;</li><li>• Increasing flexibility of production environments</li></ul>	<ul style="list-style-type: none"><li>• Reduction of start-up times, fast scale-up of production;</li></ul>	<ul style="list-style-type: none"><li>• Increasing education required for workers</li></ul>
Links between ‘Required Research and Technology’ and ‘Research recommendations’			
Required Research and Technology		Research recommendations	
Manufacturing IT as a Service: Exploit Cloud Technologies;		Reference/Open Architectures	
Cloud manufacturing/service-oriented manufacturing			
Web 2.0 connectivity vs. data exchange tools (to allow collaborative virtual enterprises to work together efficiently)		Reference/Open Architectures System and Information Integration Architectures	
Complexity management		System and Information Integration Architectures	
Security: Operational safety and reliability;		Security	
Privacy and know-how protection; Establishment of trust		Confidentiality	
Horizontal integration and optimisation of value chains		Flexible and Adaptable Manufacturing	
Managing manufacturing uncertainty in an increasingly complex value chain			
Real-time monitoring; Real-time capabilities		New Algorithms	
Factory knowledge base: virtual representation of manufacturing environments; Data consistency by means of (standardised) semantic models/system descriptions;		Modelling	
Knowledge transfer between manufacturing and engineering		Establishing of Demonstrators	
Human-centric digital age - Knowledge about human behaviour using digital media etc.		Incorporation of psychology into ICT research	
Stakeholder education (users, decision makers etc.);		Supporting Education in the field of CPS	

ICT Solution 5: Big data analysis and use for quality control			
Manufacturing Trend or Need			
Monitoring and Decision Making for Performance Optimisation	Flexible manufacturing and Supply Chain Flexibility	Cost reductions by improvements in business processes and in particular production processes	Integration of human worker in manufacturing process
<ul style="list-style-type: none"><li>• Stricter/more requirements imposed by large buyers;</li><li>• Stricter quality requirements</li></ul>	<ul style="list-style-type: none"><li>• Increasing flexibility of production environments;</li><li>• Flexibility in supply chain participation</li></ul>	<ul style="list-style-type: none"><li>• Shorter product lifecycles;</li><li>• Reduction of start-up times, fast scale-up of production;</li><li>• Greater energy efficiency</li></ul>	<ul style="list-style-type: none"><li>• Integration of human worker in manufacturing process</li></ul>
Links between ‘Required Research and Technology’ and ‘Research recommendations’			
Required Research and Technology		Research recommendations	
Improved usability: context-aware user interfaces and user-specific adaption		Reference/Open Architectures System and Information Integration Architectures	
Manufacturing IT as a Service: Exploit Cloud Technologies;		Reference/Open Architectures	
Event driven database systems and streams		System and Information Integration Architectures	
Fusion of systems and new ICT architectures (hybrid systems)			
Complexity management			
New Manufacturing IT features: support resource energy efficiency			
Big Data: Data analysis/Data fusion/data mining; Prediction/Forecasting and decision making (e.g. for factory optimisation) - local or global; Adding semantic content to unstructured data and being able to develop a responsive visualisation of data		Data Capture, Storage and Analysis	
Security: Operational safety and reliability;		Security	
Privacy and know-how protection; Establishment of trust		Confidentiality	
Intelligent components/Internet of Things (throughout the supply chain);		New or Improved low-cost, miniaturised smart sensors	
Intelligent self-powered wireless sensors to allow M2M communications, gather process data, KPIs etc.		CPPS-Cyber-Physical Production Systems	
Real-time monitoring; Real-time capabilities; Real-time monitoring; Real-time capabilities; Real-time data mining		New Algorithms	
Factory knowledge base: virtual representation of manufacturing environments; Data consistency by means of (standardised) semantic models/system descriptions;		Modelling	
Knowledge transfer between manufacturing and engineering		Establishing of Demonstrators	
Human-centric digital age - Knowledge about human behaviour using digital media etc.		Incorporation of psychology into ICT research	
Stakeholder education (users, decision makers etc.);		Supporting Education in the field of CPS	

ICT Solution 6: Joint Cognitive Systems for decision support (DSS)			
Manufacturing Trend or Need			
Monitoring and Decision Making for Performance Optimisation	Flexible manufacturing	Cost reductions by improvements in business processes and in particular production processes	Integration of human worker in manufacturing process
<ul style="list-style-type: none"><li>Increasing complexity of products, processes, and supply networks</li></ul>	<ul style="list-style-type: none"><li>Demand by customers for individualised/highly configurable products;</li><li>Increasing flexibility of production environments</li></ul>	<ul style="list-style-type: none"><li>Reduction of start-up times, fast scale-up of production</li></ul>	<ul style="list-style-type: none"><li>Lack of technology acceptance;</li><li>Extension of ICT perspective to production site/company associations;</li><li>Integration of human worker in manufacturing process</li></ul>
Links between ‘Required Research and Technology’ and ‘Research recommendations’			
Required Research and Technology		Research recommendations	
Improved usability: hide complexity from users; make complexity manageable; multi-modal user interfaces; User-centred design		System and Information Integration Architectures Reference/Open Architectures	
Complexity management		System and Information Integration Architectures	
Big Data: Data analysis/Data fusion/data mining; Prediction/Forecasting and decision making (e.g. for factory optimisation) - local or global;		Data Capture, Storage and Analysis	
(Coordination of) Autonomous manufacturing system components		Flexible and Adaptable Manufacturing	
Man-Machine-Interaction: increase ergonomics while ensuring human safety			
Development of visual encoding and artificial intelligence algorithms		New Algorithms	
Applied research in collaboration with industry in a range of subjects such as, psychology, visual design, machine learning and modelling of socio-technological systems		Applied, multidisciplinary research with large scale industrial collaboration	

ICT Solution 7: Flexible production equipment and interconnections			
Manufacturing Trend or Need			
	Flexible manufacturing	Cost reductions by improvements in business processes and in particular production processes	Integration of human worker in manufacturing process
	<ul style="list-style-type: none"><li>• Demand by customers for individualised/highly configurable products;</li><li>• Additive manufacturing/3D-printing;</li><li>• Increasing flexibility of production environments;</li><li>• Identify/anticipate changes in demand</li></ul>	<ul style="list-style-type: none"><li>• Shorter product lifecycles;</li><li>• Reduction of lead times to produce and deliver a product</li></ul>	<ul style="list-style-type: none"><li>• Integration of human worker in manufacturing process</li></ul>
Links between ‘Required Research and Technology’ and ‘Research recommendations’			
Required Research and Technology		Research recommendations	
Web 2.0 connectivity vs. data exchange tools (to allow collaborative virtual enterprises to work together efficiently)		Reference/Open Architectures System and Information Integration Architectures	
Complexity management		System and Information Integration Architectures	
Big Data: Data analysis/Data fusion/data mining; Prediction/Forecasting and decision making (e.g. for factory optimisation) - local or global;		Data Capture, Storage and Analysis	
Total customisation/ad-hoc establishment of production settings		Flexible and Adaptable Manufacturing	
Managing manufacturing uncertainty in an increasingly complex value chain			
(Coordination of) Autonomous manufacturing system components			
Man-Machine-Interaction: increase ergonomics while ensuring human safety			
Development of a self-learning, self-adapting and reconfigurable manufacturing environment			
Intelligent components/Internet of Things (throughout the supply chain);		New or Improved low-cost, miniaturised smart sensors	
Cyber-Physical Production Systems		CPPS-Cyber-Physical Production Systems	
Intelligent self-powered wireless sensors to allow M2M communications, gather process data, KPIs etc.			
Real-time monitoring; Real-time capabilities; Real-time data mining		New Algorithms	
Factory knowledge base: virtual representation of manufacturing environments; Data consistency by means of (standardised) semantic models/system descriptions;		Modelling	
Information modelling			
Standardisation of intra- and inter-machine		Interoperability and standards	

communication	
Human-centric digital age - Knowledge about human behaviour using digital media etc.	Incorporation of psychology into ICT research
Stakeholder education (users, decision makers etc.);	Supporting Education in the field of CPS

ICT Solution 8: Problem and context–centric display of only crucial information to the users			
Manufacturing Trend or Need			
Monitoring and Decision Making for Performance Optimisation	Flexible manufacturing		Integration of human worker in manufacturing process
<ul style="list-style-type: none"> <li>• Stricter quality requirements;</li> <li>• Increasing complexity of products, processes, and supply networks;</li> </ul>	<ul style="list-style-type: none"> <li>• Demand by customers for individualised/highly configurable products;</li> <li>• Enterprise mobility;</li> <li>• Identify/anticipate changes in demand</li> </ul>		<ul style="list-style-type: none"> <li>• Increasing hybrid cross-over products/embedded IT and integrated services;</li> <li>• Lack of technology acceptance;</li> <li>• Extension of ICT perspective to production site/company associations;</li> <li>• Increasing education required for workers;</li> <li>• Integration of human worker in manufacturing process</li> </ul>
Links between 'Required Research and Technology' and 'Research recommendations'			
Required Research and Technology	Research recommendations		
Improved usability: hide complexity from users; make complexity manageable; multi-modal user interfaces; User-centred design; context-aware user interfaces and user-specific adaption	System and Information Integration Architectures Reference/Open Architectures		
Developing human-centric adaptive interfaces; Research in new modalities for interaction, developing contextual awareness for different manufacturing environments	System and Information Integration Architectures		
Complexity management			
Big Data: Data analysis/Data fusion/data mining; Prediction/Forecasting and decision making (e.g. for factory optimisation) - local or global;	Data Capture, Storage and Analysis		
Total customisation/ad-hoc establishment of production settings			
Man-Machine-Interaction: increase ergonomics while ensuring human safety	Flexible and Adaptable Manufacturing		
(Coordination of) Autonomous manufacturing system components			
Intelligent components/Internet of Things (throughout the supply chain);	New or Improved low-cost, miniaturised smart sensors		

Intelligent self-powered wireless sensors to allow M2M communications, gather process data, KPIs etc.	CPPS-Cyber-Physical Production Systems
Integration of smart components for big data collection, analysis and visualisation	
Real-time monitoring; Real-time capabilities; Real-time data mining	New Algorithms
Factory knowledge base: virtual representation of manufacturing environments; Data consistency by means of (standardised) semantic models/system descriptions;	Modelling
Standardisation of interfaces and communication potentially including self-configuration	Interoperability and standards
Knowledge transfer between manufacturing and engineering	Establishing of Demonstrators
Human-centric digital age - Knowledge about human behaviour using digital media etc.	Incorporation of psychology into ICT research
Stakeholder education (users, decision makers etc.);	Supporting Education in the field of CPS

ICT Solution 9: Engineering Platform for design / ops continuum			
Manufacturing Trend or Need			
Monitoring and Decision Making for Performance Optimisation	Flexible manufacturing and Flexible Supply Chains	Cost reductions by improvements in business processes and in particular production processes	Integration of human worker in manufacturing process
<ul style="list-style-type: none"><li>• Stricter/more requirements imposed by large buyers;</li><li>• Increasing complexity of products, processes, and supply networks;</li></ul>	<ul style="list-style-type: none"><li>• Demand by customers for individualised/highly configurable products;</li><li>• Virtualisation and digitisation;</li><li>• Enterprise mobility;</li><li>• Transparency of environmental footprint across supply chain;</li></ul>	<ul style="list-style-type: none"><li>• Reduction of start-up times, fast scale-up of production;</li></ul>	<ul style="list-style-type: none"><li>• Increasing hybrid cross-over products/embedded IT and integrated services;</li><li>• Extension of ICT perspective to production site/company associations;</li><li>• Integration of human worker in manufacturing process</li></ul>
Links between ‘Required Research and Technology’ and ‘Research recommendations’			
Required Research and Technology		Research recommendations	
Cloud manufacturing/service-oriented manufacturing		Reference/Open Architectures	
Complexity management		System and Information Integration Architectures	
Big Data: Data analysis/Data fusion/data mining; Prediction/Forecasting and decision making (e.g. for factory optimisation) - local or global;		Data Capture, Storage and Analysis	
Dig data analysis and categorisation, big data analytics for both production processes and product usage			
Security: Operational safety and reliability;		Security	
Secure cloud platform development			
Privacy and know-how protection; Establishment of		Confidentiality	



trust	
(Coordination of) Autonomous manufacturing system components	Flexible and Adaptable Manufacturing
Intelligent components/Internet of Things (throughout the supply chain);	New or Improved low-cost, miniaturised smart sensors
Miniaturisation of smart, low cost new or improved sensors	
Intelligent self-powered wireless sensors to allow M2M communications, gather process data, KPIs etc.	CPPS-Cyber-Physical Production Systems
Factory knowledge base: virtual representation of manufacturing environments; Data consistency by means of (standardised) semantic models/system descriptions;	Modelling
Unified engineering exchange of data	
Standardisation of product – process – service description	Interoperability and standards
Development of standards with universal acceptance	
Knowledge transfer between manufacturing and engineering	Establishing of Demonstrators
Human-centric digital age - Knowledge about human behaviour using digital media etc.	Incorporation of psychology into ICT research
Stakeholder education (users, decision makers etc.);	Supporting Education in the field of CPS

ICT Solution 10: Supply chain visibility and decision assistance			
Manufacturing Trend or Need			
Monitoring and Decision Making for Performance Optimisation	Flexible manufacturing and Flexible Supply Chains		Integration of human worker in manufacturing process
<ul style="list-style-type: none"><li>• Stricter/more requirements imposed by large buyers;</li><li>• Stricter quality requirements;</li><li>• Increasing complexity of products, processes, and supply networks</li></ul>	<ul style="list-style-type: none"><li>• Increasing flexibility of production environments;</li><li>• Flexibility in supply chain participation;</li><li>• Transparency of environmental footprint across supply chain</li></ul>		<ul style="list-style-type: none"><li>• Extension of ICT perspective to production site/company associations</li></ul>
Links between ‘Required Research and Technology’ and ‘Research recommendations’			
Required Research and Technology		Research recommendations	
Manufacturing IT as a Service: Exploit Cloud Technologies;		Reference/Open Architectures	
Improved usability: hide complexity from users; make complexity manageable; multi-modal user interfaces; User-centred design; context-aware user interfaces and user-specific adaption		System and Information Integration Architectures Reference/Open Architectures	
New Manufacturing IT features: support resource energy efficiency		System and Information Integration Architectures	
Complexity management			
Big Data: Data analysis/Data fusion/data mining; Prediction/Forecasting and decision making (e.g. for factory optimisation) - local or global;		Data Capture, Storage and Analysis	

Total customisation/ad-hoc establishment of production settings	Flexible and Adaptable Manufacturing
Horizontal integration and optimisation of value chains	
Managing manufacturing uncertainty in an increasingly complex value chain	
(Coordination of) Autonomous manufacturing system components	
Intelligent components/Internet of Things (throughout the supply chain);	New or Improved low-cost, miniaturised smart sensors
Intelligent self-powered wireless sensors to allow M2M communications, gather process data, KPIs etc.	CPPS-Cyber-Physical Production Systems
Real-time monitoring; Real-time capabilities; Real-time data mining	New Algorithms
Factory knowledge base: virtual representation of manufacturing environments; Data consistency by means of (standardised) semantic models/system descriptions;	Modelling
Develop information models	
Standards development	Interoperability and standards
Development of early demonstrators to validate possible solutions	Establishing of Demonstrators
Knowledge transfer between manufacturing and engineering	
Human-centric digital age - Knowledge about human behaviour using digital media etc.	Incorporation of psychology into ICT research
Stakeholder education (users, decision makers etc.);	Supporting Education in the field of CPS

ICT Solution 11: Security solutions for collaborative networks			
Manufacturing Trend or Need			
	Flexible manufacturing		
	<ul style="list-style-type: none"><li>Virtualisation and digitisation</li></ul>		
Links between ‘Required Research and Technology’ and ‘Research recommendations’			
Required Research and Technology		Research recommendations	
Manufacturing IT as a Service: Exploit Cloud Technologies;		Reference/Open Architectures	
Cloud manufacturing/service-oriented manufacturing			
Web 2.0 connectivity vs. data exchange tools (to allow collaborative virtual enterprises to work together efficiently)		Reference/Open Architectures System and Information Integration Architectures	
Security: Operational safety and reliability		Security	
Develop credible security strategies for companies			
Develop security options with clear cost/benefit ratios			
Privacy and know-how protection; Establishment of trust		Confidentiality	
Horizontal integration and optimisation of value chains		Flexible and Adaptable Manufacturing	
Investigate all common standards and common standards derived from existing industry specific standards		Interoperability and standards	

## 13 Appendix 3: References

<sup>i</sup><http://www.iosb.fraunhofer.de/servlet/is/48960/Begriffsdefinitionen%20des%20VDI%20GMA%20FA7%2021.pdf?command=downloadContent&filename=Begriffsdefinitionen%20des%20VDI%20GMA%20FA7%2021.pdf>

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