Road4FAME - Orientation Paper

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Summary and Key Recommendations

The key recommendations identified by the Road4FAME project are there is a need for research into the following topics:

a) Real-time data acquisition and analysis
b) Network-centric communication and collaboration between players, humans and systems across the entire value chain
c) Scalable Cyber Physical System architectures for adaptive and smart manufacturing systems, and additionally
d) Cross-cutting and non-functional challenges
    - Interoperability standards,
    - Semantic mechanisms
    - Data visualization
    - Sociotechnical issues
    - Training and education
    - Cybersecurity

The orientation paper is divided into 4 sections, firstly defining the context of the term "manufacturing" as considered in this paper, introducing the 4 Road4FAME scenarios which have been used as the basis of the Road4FAME Roadmapping work, the challenges and research recommendations identified by the Road4FAME expert group and finally, the impact that addressing these issues would have on the manufacturing industry.

Definition of Manufacturing and Related Terminology [1,2,3]

Traditionally, manufacturing has been defined as the production process of transforming raw materials into useful products and goods. Nowadays, although physical production is often at the centre of a wider manufacturing value chain, manufacturing goes beyond this encompassing production, research, design and service provision. Manufacturers are frequently using this wider value chain to generate new and additional revenues. The exploitation of ICT-based solutions across the manufacturing process chain is used to make manufacturing efficient. Both in combination to allow for a more personalized, diversified and mass-produced product portfolio and also for flexible reaction to market changes. Staying ahead of the competition ensures Europe's competitiveness.

Digital manufacturing assumes a key role for innovation and growth. Productivity growth is essential for returning to a sustainable growth path. As productivity growth is a compounding measure for European economies to escape the financial crisis – small improvements on an annual basis make large differences over the long term. When looking at ways of boosting productivity, the role of digital technologies and greater adoption of Information and Communications Technology (ICT), mostly in non-ICT sectors, is relevant to drive the productivity growth Europe needs (Lisbon council, 2014).

There are many different definitions of manufacturing. Some recent ones are presented below:

> 'The new era of manufacturing will be marked by highly agile, networked enterprises that use information and analytics as skillfully as they employ talent and machinery to deliver products and services to diverse global markets' (McKinsey & Company, 2012 – [4]).
>
> 'The application of leading-edge technical knowledge and expertise for the creation of products, production processes and associated services, which have strong potential to bring sustainable growth and high economic value to the UK. Activities may stretch from R&D at one end to recycling at the other' (Technology Strategy Board, 2012- [5]).
>
> Digital Technologies such as Cyber Physical Systems, Internet of Things and Machine to Machine communication, are radically changing business and industrial processes, enabling entire new classes of products and services. ICT will decentralize production by enabling flexible, programmable and embedded forms of manufacturing, by synchronizing complex, high-end production systems, and by creating highly innovative value chains that cut across traditional sectors and domains [Dutch Agenda – Smart Industry, 2014].

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[1] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/283900/ep26-future-manufacturing-international-approaches.pdf
[2] http://www.ifm.eng.cam.ac.uk/uploads/Research/CIG/HVM_summary_000.pdf
[3] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/255923/13-810-future-manufacturing-summary-report.pdf
[4] http://www.mckinsey.com/insights/manufacturing/the_future_of_manufacturing
[5] „A landscape for the future of high value manufacturing in the UK", TSB (2012) - https://www.innovateuk.org/documents/1524978/1814792/A+landscape+for+the+future+of+high+value+manufacturing+in+the+UK/0ffe7684-2f8c-4038-89b3-290c1085389d

Industry 4.0 is stated as the 4th industrial revolution by the German Industry 4.0 platform which has been established by major public and private initiatives. Figure 1 shows the previous revolutions in manufacturing, which were caused by steam engines, assembly-line work, and electronics and automation. The 4th industrial revolution, i.e. industry 4.0 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 the resulting consequences for the adding value, the business models and the subsequent services and work organisation.

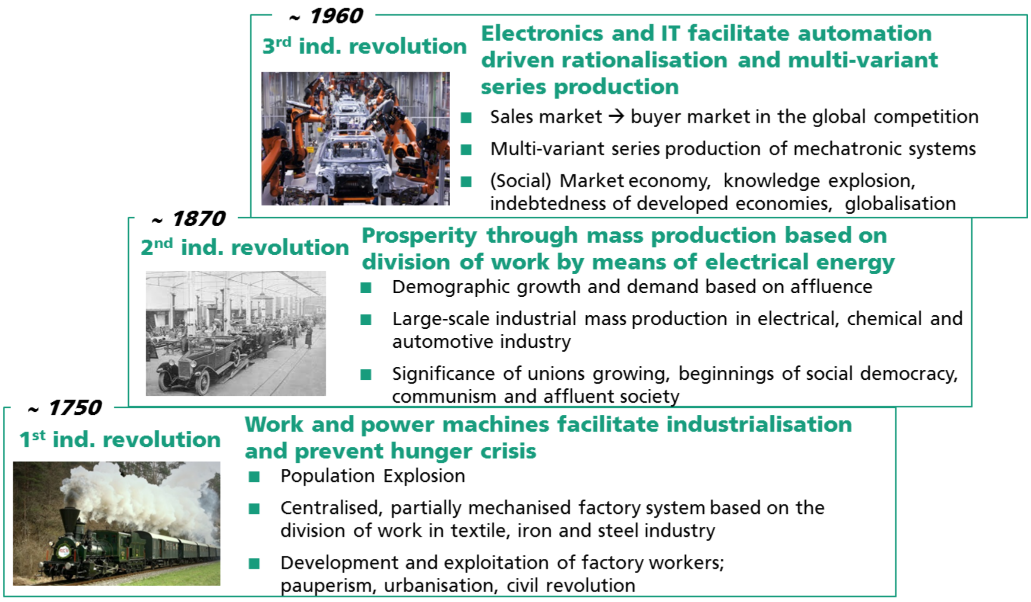

Image sources: AUDI auto-medienportal.net; DFKI; bahnbilder.de

Fig. 1 Previous Major Developments in Manufacturing Environments

‘The world is in the midst of a paradigm shift in the 21st century – one that integrates diverse sets of ideas, products and services globally through the lens of highly complex, integrated and self-morphing resource webs… Highly talented skilled people are necessary to effectively and consistently apply cutting edge science and technology, systems thinking, smart services and processes, and supply chain excellence’ (Deloitte, 2013 –[6]).

These definitions highlight either **the systems-nature** of manufacturing or particular technological and/or organizational enablers that are **sources of competitive advantage**. Additionally, the term High Value Manufacturing (HMV) may also be used.

[6] http://www.deloitte.com/assets/Dcom-Global/Local%20Assets/Documents/Manufacturing/dttl_2013%20Global%20Manufacturing%20Competitiveness%20Index_11_15_12.pdf

Road4FAME Manufacturing Scenarios:[7]

In Road4FAME, the needs and requirements of manufacturing companies are identified under particular consideration of four manufacturing scenarios (See Fig. 2). These scenarios have been constructed in a way so they are a) challenging and b) not yet possible today, i.e. of a certain visionary nature. Companies in each manufacturing scenario likely face similar challenges and likely have similar needs and requirements regarding manufacturing IT. The four scenarios are not alternative visions of future manufacturing but rather describe interesting and important manufacturing settings with which manufacturing companies are likely to increasingly identify in the future. The four scenarios are not mutually exclusive so a manufacturing company may be able to identify with aspects of more than one scenario. The following provides a brief description of each scenario and outlines the challenges which each scenario entails.

Fig. 2 Road4FAME Manufacturing Scenarios

Scenario 1: The Manufacturing-as-a-Service Enterprise

The MaaS enterprise does not sell products, but offers manufacturing as a service. The manufactured goods are complex and fully customized. It frequently faces short-notice requests of high volume. The considered MaaS needs to be able to quickly reconfigure and scale up its production, to establish close information exchange with customers, i.e. integrate with other businesses and enter into business agreements, and cooperate with the new partners in order to fulfil new orders

[7] = WHAT, to be transformed into section "a) Challenges"

appropriately. The range of offered services goes beyond pure manufacturing process, extending over all the value chain e.g. product design, after sales support, product maintenance.

One key asset of IT is a full digital representation and virtualisation of the manufacturing cycle, covering CAx tools, engineering, prototyping, production and qualification phases to target WYSWYG paradigms. Digitization of, for example, product quality, user-characteristics and production parameters based on sensory systems will also be crucial to new innovations in the production process, products and services. Digital tools are instrumental to ensure de-coupling of design and production steps. One example is the model of semiconductor foundries, one other prominent example would be 3D printing, but traditional processes like CNC gradually adopting similar principles.

The company offers its manufacturing services globally and is strongly dependent on an efficient mechanism for service provision. The company's strategic plan is to be able to anticipate changes in demand from the customers, keeping the pace of technological progress in the sector and to improve the companies' ability to take orders ad-hoc. Predicting trends on demand will require using data mining on a variety of data coming from many sources, e.g. social networks.

Scenario 2: The Virtual Enterprise

The virtual enterprise is an association of companies which cooperate ad-hoc to react to market opportunities, to do research together, innovate products and to minimize costs and risks for approaching new markets with new products. Companies will also seek to ensure the flexibility of their complex supply chain and the fast re-configurability of their production lines (e.g. through self-adaptive and modular machine tools and robots) to meet changing consumer requirements. The involved companies have to join forces effectively to really form one business out of many. The virtual enterprise would be established ad-hoc around a short term request and dissolve after the satisfaction of the request. As capabilities might replicate capacity in multiple partners, they will need to bid internally for selection.

ICT has enabled improved, geographically distributed manufacturing processes underpinned by knowledge management systems able to cope with the entire production cycle from design to sales and service supply. The role of IT is to enable full virtualization of resources through an interoperable platform that connects and synchronizes critical business processes along the value chain, that aligns priorities, makes transparent resource demand and supply, exchanges information of critical product and production data to accommodate for fast ad-hoc decision making.

A virtual enterprise consisting, e.g. of SMEs would enable them to complement each other's strengths or to attain the capacities of large enterprises. A virtual enterprise consisting of both large and small companies enables to combine strengths, i.e. the large companies bring in their capacity, and the small companies bring in their flexibility and innovation power. Also, the virtual enterprise enables a much broader product and service portfolio than any individual company could provider alone. The Virtual Enterprise is often confined to a regional eco-system for which ICT communication and sharing provide means for networking, collaboration and integration. Companies will be required to engage in regional based operations to better and faster fulfil local demands such as highlighted by regional manufacturing of fashion products in countries such as Italy.

Scenario 3: The High-Volume/High-Value Production Enterprise

This scenario describes a company which produces high volumes of high–value goods and increasingly faces the challenge of shorter product life-cycles. To remain competitive, it also needs to be capable of offering an increasing degree of customization, despite the high volumes produced (mass customization). The supply network the company is embedded within comprises some long-term cooperation but also ad-hoc cooperation.

As product development, production planning and engineering, production execution and manufacturing services are converging – thanks to process digitalization and cutting-edge software tools – the product quality, the degree of customization and development speeds increase while maintaining competitive prices. In this scenario, the level of automation is high in the plant, and the customization of production requires short reconfiguration cycles, including tests / experimental production, fast re-programming of machines and frequent updates of information to the workers who need to be skilled and also frequently re-trained, as well as short ramp-up and scale-up cycles. ICT would support and drive convergence of MES and enterprise IT systems to establish a de-centralised, flexible automation architecture. In this case, context-awareness of production facilities and moving decisions to the point of interest (i.e. close to the sensor and monitoring system) is important in order to adapt in real time the production to current product specifications, react to and schedule order execution appropriately, also according to specific customer relations. A network centric approach to production will replace linear production processes. These networks will interconnect parts, products and machines across production plants, companies and value chains at a highly granular level. The German vision of the Industry 4.0 predicts the 4^{th} industrial revolution for networked and smart production architectures.

The Digital Factory is not only about more advanced sensor information and monitoring systems with high granularity levels. It is also key to drive further data aggregation and automation, together with next generation control systems. New ways of pattern recognition, data analytics and predictive modelling can even lead to fully automated facilities and to smart and automated ways to support production assistants and decision making in any situation and context. .The fact that a company has to react to an increasingly dynamic market entails also that the individual worker has to keep this pace, by acquiring relevant knowledge fast enough. With the half-life of relevant knowledge decreasing, the rate of human knowledge acquisition threatens to become the limiting factor for companies to keep pace with technological progress. Appropriate IT support has to be provided to the human who is embedded in the digital factory, in the form of context-relevant information and on-the-fly knowledge provision supported by, e.g., knowledge based decision support systems or self-learning systems supported by cooperation between humans, machine and data.

Scenario 4: The Green Enterprise

This scenario describes a company to which environmental awareness is an important part of the company image. But the company's goal is to go beyond a mere "green washing" of its image and products to really introducing environmental sustainability as a key parameter in all steps of the product life-cycle, including sourcing and recycling. Based on the consideration of data from a large number of sources, real-time information about the footprint of manufacturing processes is available to steer production towards minimal environmental impact. Keeping record of the origin and history of raw materials as additional aspect of environmental awareness is used as a marketing advantage. Buyback of products for recycling or product rental and return to recycle policies are strategic, increasing sustainability on sourcing and creating stronger bonds with customer.

The environmental footprint of ordered, customized products is available to customers in the customization step, so the footprint generated along the value-chain is transparent to the customer and environmentally aware buying decisions can be made. To the manufacturer and the customer, the environmental footprint is available and can be taken into account as an actual decision parameter. The environmental implications of design, process, and buying decisions become completely transparent.

With a certain customer segment increasingly demanding such transparency, the competitiveness of the company increasingly depends on the degree of transparency it is able to provide, and the level of environmental sustainability it can demonstrate. Thus, its capability to be “green” translates into tangible economic value.

Minimization of resource consumption and energy efficiency is a critical performance indicator especially for the continuous process industry like pharmaceutical, chemical, food, metal processing. In particular, adapting energy demand and supply could result in major economies.

Challenges and Research Recommendations

The following research areas have been identified by the Road4FAME project as being key for supporting the future manufacturing scenarios presented:

- Real-time data acquisition and analysis
- Network-centric communication and collaboration between players, humans and systems across the entire value chain
- Scalable Cyber Physical System architectures for adaptive and smart manufacturing systems, and additionally

In addition, a number of cross-cutting and non-functional challenges have been identified and research into Interoperability standards, semantic mechanisms, data visualization, sociotechnical issues, training and education, cybersecurity is also recommended.

In the following sections the rationale behind these recommendations is given along with further detail on the challenges being addressed.

Key challenges for manufacturing companies:[8]

Over the last decades, manufacturing companies have been implementing point-solutions, each bringing a specific feature or fixing a specific issue. Resulting from this approach is in many cases a highly heterogeneous manufacturing IT landscape. While these IT landscapes are already costly to administer, further addition of capabilities becomes even more costly because they have to be fitted into the heterogeneous IT landscape already existing. This is a main reason why the majority of manufacturing companies are usually well behind the latest manufacturing IT technology. This indicates that it is usually not the *unavailability* 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 as well as complexity and lack of capacity / IT expertise due to the very high implementation costs. Without approaches to overcome this situation, or lessen the impact of it, manufacturing IT innovation will always be doomed to happen slowly.

Manufacturing companies are increasingly facing the challenge to be flexible and offer highly customized products. Furthermore, manufacturing companies, especially SMEs, are confronted with ever stricter requirements from larger buyers, e.g. for tracking and tracing capabilities, or resource efficiency information. All these challenges are not only relevant today, but can be expected to further increase in relevance in the future. Manufacturing IT solutions need to be available to support manufacturing companies, especially SMEs, in responding to these challenges successfully and without daunting implementation costs, thereby maintaining and boosting their competitiveness locally and in the increasingly globalized markets they participate in.

[8] = WHAT, to be transformed into section “a) Challenges”

Real time data acquisition and analysis

Within manufacturing there is a continuous drive for efficiency and quality. Digitisation will further evolve and is brought to another level within a Digital Factory. Not only will it enable communication between all partners in the value chain, but digitisation of, for example, product quality, user-characteristics and more sophisticated production parameters based on advanced sensory systems will also be crucial to new innovations in the production process, products and services. Underlying this is a need for improved situational awareness throughout the factory and the supply chain. This can only be achieved via much greater levels of data acquisition throughout the process and the use of this data for optimization, decision support and distributed control. Here there is a great opportunity for introduction of novel, easy to install, low cost, sensor technologies and monitoring concepts. If wireless monitoring is to be used there is also a need for ultra-low power electronics and energy harvesting technologies to avoid the need for, and associated maintenance costs of, battery change. An increase in data gathering will also require robust wired and wireless communication protocols that can deal with efficient transmission of individual data values from a multitude of sensors to streaming of data at high data rates, e.g. for vibration and video monitoring. A challenge for the future will be the physical system integration of highly complex acquisition systems and management of the data deluge from the myriad of installed sensors throughout the plant and the fusion of this with other information sources within the factory and supply chain. Here there is a need for visualization tools to manage the complexity of the data produced allowing managers to understand the "real world in real time", manage risk and make informed decisions on how to control and optimize the manufacturing process.

Network-centric communication and collaboration between players, humans and systems across the entire value chain

Three main drivers are pushing forward the distribution of manufacturing and flexibility of production networks: globalization, companies increasingly focusing on their core business, and decreasing lot sizes. These trends increasingly require fast and flexible establishment and reconfiguration of production networks to maintain the competitiveness of involved companies. In order to achieve this, organisations, humans, and systems have to communicate, share information in real time and collaborate seamlessly across value chains.

Production networks link companies in networks, with an active input in communication and organisation of the work of other organisations. Individual entrepreneurs have to shift their focus more and more to the added value of the value chain or network as a whole. Cloud services are promising technologies to organise information throughout the value chain, giving companies direct access to logistics information from other organisations. This approach should be extended to information about manufacturing, enabling active inter-company synchronization of production data, process information and parts delivery. As a result, organisations will become more dependent and compete together as almost a single entity.

In particular, relevant infrastructures and platforms have to be established which provide interoperability throughout supply networks on business and system level with regard to syntax and semantics (protocols). ICT security, solutions for IP protection and the establishment of trust in collaborative cloud infrastructures are needed to ensure viability and acceptance of those infrastructures and platforms.

Another important aspect is the definition of collaboration models. This goes beyond just providing communication and protocols but also needs to consider regulations, governance, advanced supply chain decision support and global optimisation including mechanisms to balance fairness.

Scalable CPS architectures for adaptive and smart manufacturing systems

Future ICT tools and technologies have various opportunities such as increases in efficiency and quality throughout value chains, or the exploitation of additional markets, and manufacturing specifically addressing current market and customer demands. Smart manufacturing will exploit advances in wireless sensor technologies, M2M communication and ubiquitous computing, that would allow to track and trace each individual part of the production and monitor the individual phases. Together, an internet-style network of interconnected, intelligent machines are termed Cyber Physical Systems (CPS) (See Fig. 3) which according to the *industry 4.0 glossary of the VDI committee for industry 4.0*[9]*,* is a system which interlinks real (physical) objects and processes with information processing (virtual / cyber) objects and processes by means of open and distributed networks. Additionally, a CPS can use local or remote available services, or provide man-machine-interaction. Especially when it comes to networked CPS, additional features like dynamic reconfiguration, continuous evolution, partial autonomy, and emerging behavior of CPS networks become important, too[10].

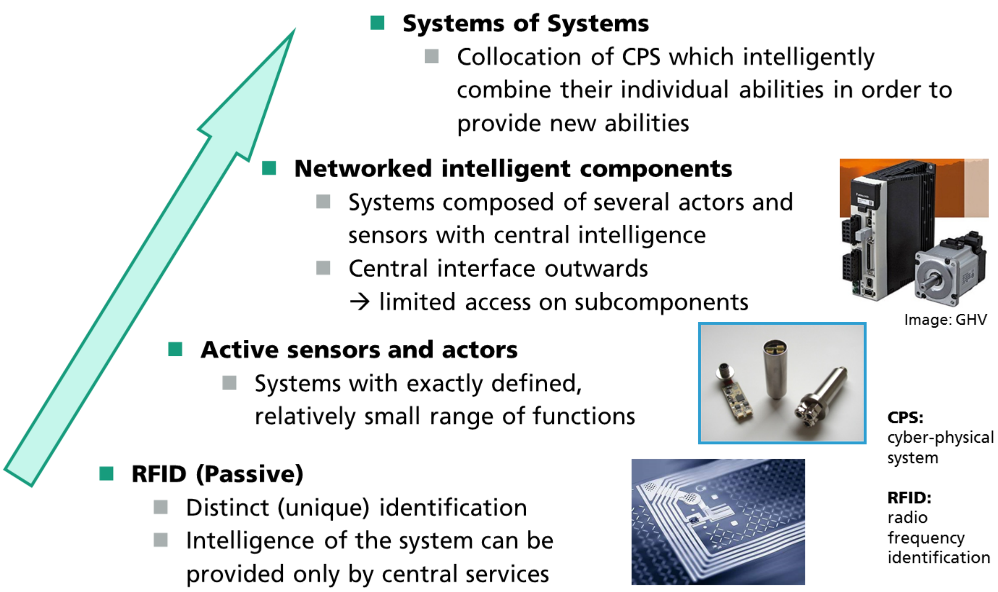

Fig. 3 CPS Stages of Intelligence (© Fraunhofer IPA)

[9]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

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

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:

- Software systems such as CAx, PLM, ERP, MES. Nowadays, integration of those systems comes along with high efforts for customization, i.e. configuration and implementation of interfaces which enable the necessary data exchange. However, to achieve integration and migration to new systems or features faster, architectures are required which enable seamless integration, e.g. by supporting information integration through industrial data standards and agreed ontologies rather than system integration. This should also consider closed loops, e.g. to enable lifecycle related optimization.
- Automation systems throughout all layers from Sensor level, to Internet of Things and CPS level, as well as machine controls, MES, and ERP systems (refer to ISA 95 for typical current system layers). Integration of those systems nowadays usually takes place hierarchically, often also via proprietary or industry specific protocols and data formats. As a result, efforts for integration or reconfiguration of automation systems are quite high. To overcome this issue, advanced architectures are required which enable seamless integration and low-effort (re-) configuration of systems throughout all layers (including software systems above), as well as direct communication among intelligent components as it is required e.g. for distributed system components.

For both of these integration/migration challenges, appropriate IT architectures have to be developed and established (including the migration from existing ones) in practice. While doing so, aspects to be considered include real-time capabilities, interoperability among systems and components, adaption (e.g. to varying governance structures), scalability (i.e. number of systems/components integrated), and flexibility (i.e. kind of systems/components to be integrated), etc. Approaches to be taken into account to achieve this are solutions based on M2M technologies, service-orientation in information and automation integration, and cloud paradigms and infrastructures.

The convergence of cloud and IoT technologies will facilitate the development factories of the future, these future manufacturing plants will comprise a numerous of devices, physical and virtual smart objects, internally and externally interconnected to dynamically enable the configuration and monitoring the operational capabilities of the plant, or networks of plants, the quality control and efficiency improvement. Additionally, the traditional phase: design, produce and customer fulfillment is fragmented and it will be replaced by a close loop management of the end to end design - customer fulfill, where cycles are shorter and products are designed based on customer requirements. The process do not finish with the product delivery, the product-service provides information for the maintaining services and for continues design of products and processes and the sensors in machineries and manufacturing service developed will facilitate the operational performance model for predictive maintenance of the machinery.

A global plant floor requires that the network of production facilities operates such as a single virtual plant. Operations require individual plants centralization control capabilities based on real-time information, Multi-plant Manufacturing Execution Systems (MMES) and major integration and visibility on supply-customer ecosystems based on Enterprise Manufacturing Intelligence (EMI) platforms. Additionally, increase of control and supervision requires improve and speed up the decision making capabilities based on real-time information, interoperability between systems and collaborative decision making. This environment requires adaptive and scalable architectures to support real-time data for operational management, the supply chain execution and collaborative decision-making. Scalable and multi-enterprise architectures for managing the operations of network of organizations in the same supply chain and connecting MES and business processes in real time and establishing new business models based on secure cloud services.

Manufacturing digitalization is a reality and the digital enterprise is changing all areas of industry using CPS and internet technologies such as cloud-based services, data analytics, mobility, social media and smart devices. Due to the increase of complexity in manufacturing, the marketplaces offer will satisfy the demand of services and applications based on cloud infrastructure.

Cross cutting and non-functional challenges

In addition to the three main research areas highlighted above there are a number of cross-cutting and non-functional challenges of general interest that also need to be addressed acros the board. These include:

- Interoperability standards: covering protocols, syntax, and semantics are necessary to interconnect various systems throughout all levels (from smart objects to supply chain management level). This would enable fast and faultless integration of CPS and manufacturing IT systems in both a horizontal sense, e.g. various partners in a production network, and also from the vertical perspective, e.g. from the sensors and equipment to the supply chain management system, allowing fast reaction to changing commercial demands and conditions. We therefore recommend that the EC funds CSAs concerned with:
    - Supporting the definition and harmonization of Systems of Systems integration standards (e.g. for the manufacturing domain), considering vertical and horizontal integration aspects.
    - Supporting the creation of guidelines for fast adaption of the developed interoperability standards and their integration with business processes.
    - Supporting the set-up of consistent evaluation environments showing the benefits of the newly defined / harmonized standards.
    - Supporting and monitoring the implementation of strategies for standard-roll-out and development, which make sure that standards are accepted by industry and applicants (e.g. due to reduced complexity, coverage of domain-specific requirements, acceptance and implementation by key players, etc.)

- Beyond standards, semantic mechanisms are needed which enable easy exchange of information and data integration of legacy systems and systems from different domains (e.g. standards are mostly specific for industry branches). Semantic technologies like ontologies for data acquisition, knowledge elicitation and information exchange have to support the mapping of information representation throughout different systems and domains. In addition, research is also required into self-descriptions of CPS /components/systems providing information on capabilities and access information for interfaces.

- Data visualization is necessary to deal with complexity & support of human decisions. Here there are requirements for appropriate visualization methodologies for large amounts of information (filtering etc.) and to extract potential relationships. Additionally, there is a need for role-based/user-specific views to present the most appropriate and relevant information to users.
- Addressing sociotechnical issues is a major factor in successful deployment of new technologies and a key element and this is the HMI which is the primary interface between humans and the system. The objective is to provide HMI's that are intuitive to use and modular so that they can be configured to support application and task specific user interfaces.
- Training and education is an important underpinning activity. This needs to address decision makers, the engineers who are developing and deploying systems and end users to achieve an awareness and acceptance of new technologies
- Cybersecurity[11], in particular, represents a critical and complex cross-cutting challenge. According to Microsoft, "business value is found in more connected systems—and is increased when more data is available to be analyzed—making security more difficult and costly. The more devices connecting to a system, the more vulnerable that system becomes. Data security is also more complicated with more systems using the same data source for different types of analytics, yet each system has its own unique vulnerabilities and consumes data differently."[12] As the IoT expands, cybersecurity will have to be considered at every point and common, sector specific threats or threat model will need to be identified. Security requirements that are unique to CPS will have to be determined. A cybersecurity risk management framework and methodology to enable, assess, and assure cybersecurity for adaptive and smart manufacturing systems will have to be established; adaptable computational and storage tools including methods for protection and security of intellectual property will have to be identified, developed, and deployed. Novel information security concepts and/or approaches, such as turning properly constructed interfaces from attack surfaces[13] into cyber-defense surfaces, offering explicit and implicit design guarantees[14], and providing security as a class of interface guarantee, will have to be explored. It will be much more effective and ultimately cheaper to secure smart manufacturing systems at the engineering design phase[15], rather than later. The economic and technical viability of possible integration with legacy systems as well as existing open source applications and tools will also have to be assessed.

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[11] Within the context of manufacturing scenarios, cyber security is defined as "the protection of information (on computers and networks) against unauthorized disclosure, transfer, modification, or destruction" by SMLC (http://smartmanufacturingcoalition.org).
[12] http://www.microsoft.com/windowsembedded/en-us/intelligent-systems.aspx
[13] https://en.wikipedia.org/wiki/Attack_surface
[14] https://en.wikipedia.org/wiki/Design_by_contract
[15] "Sicherheitskonzepte für Industrie 4.0 können nicht im Nachgang eingeflickt werden, sondern müssen schon bei der Gestaltung der Gesamtlösung im Sinne des Security by Design berücksichtigt werden." Security-Anforderungen für Industrie 4.0 (http://www.konstruktion.de/themen/antriebstechnik/security-anforderungen-fur-industrie-4-0/)

Impact of Addressing these Challenges for the Manufacturing Industry

If the challenges outlined in the previous sections are successfully addressed the expectation is that the research would contribute and enable the following capabilities:

- Novel approaches to provide manufacturing IT capabilities swiftly and at low implementation costs so that new functionality can be incorporated *if*, *when* and *as* needed. This involves dealing successfully with the heterogeneity of the existing IT landscape in manufacturing companies. (Some keywords in this regard are: interoperability solutions, semantic interfaces, abstraction layers, modularity / apps / out-of-the-box solutions / plug-and-play, migration strategies)
- Enabling flexibility at factory level and across supply chain: Semantic technologies and self-learning capabilities to support re-configurability at shop-floor level. Seamless integration across the supply chain to guarantee quick adaptation to new customization of products.
- Enabling traceability: Approaches are to be investigated to feasibly provide tracking/tracing capabilities even for manufacturers which do not manufacture at a high level of automation. (Some keywords in this regard are: retrofitting, robust self-powered wireless sensors)
- Enabling optimization of resource efficiency, decision making, predictive maintenance: Approaches are to be investigated to feasibly introduce and operate monitoring infrastructures with a very large number of sensors. (Keywords in this regard are: connectivity, data acquisition, integration with decision making applications, data fusion, real-time data processing, real-time decision making)

These in turn would directly have an impact and provide financial benefits to manufacturing companies through:

- Acceleration of deployment of IT innovation at manufacturing companies by making manufacturing IT innovation not only available but also accessible for manufacturing companies, especially SMEs, by means of drastically reduced implementation costs.
- Out-of-the-box availability of IT solutions for smaller and medium sized manufacturing companies, enabling them to be more flexible, offer higher degrees of customization and respond successfully to the increasing requirements for tracking and tracing capabilities or resource efficiency.
- Transfer of solutions from the wider IT domain to manufacturing domain, thus cross-fertilizing the manufacturing domain with IT solutions from other IT fields.

Considering the research recommendations presented the specific impacts with respect to the identified research priorities are:

- **Real time data acquisition and analysis**
  The introduction and wide spread use of real time data acquisition and analysis will fundamentality change manufacturing giving rise to much better monitoring and control of the process chain. Coupled with innovative visualization, analysis and decision support tools great improvements can be made in efficiency and quality while at the same time identifying and managing risk within the manufacturing process and the supply chain.

- **Network-centric communication and collaboration between players, humans and systems across the entire value chain**
  Seamless integration of organisations, humans, and systems throughout manufacturing networks is the major precondition for fast and flexible establishment and reconfiguration of production networks which is needed to sufficiently respond to trends like shortening product lifecycles and product individualization. While doing so, it will facilitate the implementation of innovative business models and exploitation of (additional) market potentials.

- **Scalable CPS architectures for adaptive and smart manufacturing systems**
  CPS architectures and smart manufacturing systems development in manufacturing will improve organization, monitoring and control of business processes making it more flexible and adaptable to changing conditions. It will facilitate the creation of new business opportunities in manufacturing for manufacturing service provision, production processes closer to customer, lower barriers to new entrants for applications and services development that will facilitate to SMEs access to new technologies and services at lower costs.

- **Cross cutting and non-functional Issues**
  In addition, a number of cross-cutting and non-functional challenges have been identified and research into Interoperability standards, semantic mechanisms, data visualization, sociotechnical issues, training and education, cybersecurity is also recommended.

References and Sources of Information

In compiling this orientation paper the following references and sources of information have been considered as highlighted in the following sections.

[1] Road4FAME documents

The recommendations above are based on to-date Road4FAME findings obtained in expert interviews and workshops, and by contrasting these findings with own analyses of trends (D2.3), research landscapes (D1.1) and strategy documents (D1.2). The documents listed below summarize these findings. They are publicly available at www.road4fame.eu/resources.

- D2.2: Needs and requirements in manufacturing business settings:
  This document presents an overview of challenges and needs of the manufacturing domain which was established by conducting interviews with representatives of manufacturing companies and manufacturing IT solutions providers. In a multi-step process, 37 representatives of manufacturing businesses and manufacturing IT solution providers were involved in face-to-face interviews and telephone interviews of 20-40 minute duration. Input from two workshops with the Road4FAME Experts Group contributes to this document as well.
- D1.3: Overview of technology push and application pull regarding architectures and services:
  Whereas most previous deliverables constitute separate building blocks for establishing either the push perspective (D1.1, D1.2) or the pull perspective (D2.2. D2.3), this document is to analyse them jointly, thereby joining push and pull perspective. Beyond the material from previous deliverables, input received at two workshops with the Road4FAME Experts Group is also considered for the analysis.
- D3.2 Initial Roadmap:
  This deliverable summarizes and analyses the input from our previously held roadmapping workshops and illustrates an initial version of the Road4FAME roadmap.

The recommendations/opportunities under are derived from the Road4FAME recommendations as presented at the 'Roadmap Meeting' in Brussels (11/7/2014).

a) topic a: Real time data acquisition and analysis
b) topic b: Network-centric communication and collaboration between players, humans and systems across the entire value chain
c) topic c: Scalable CPS architectures for adaptive and smart manufacturing systems

Top Four ICT Manufacturing Solutions

- Real time data acquisition and analysis ***(related to topic a)***
  This includes advanced MES systems, production monitoring in real time, distributed ICT systems for collecting resource utilization on individual machines, open data and system integration platform for unstructured data environment and capability for big data analysis and use especially for quality control
- ICT platform for advanced supply chain decision support ***(related to topic b)***

This includes advanced support services and platforms for collaborative working and supply chain visibility and performance data to assist decision

- Interoperability and standards ***(related to topic b)***
  This includes interoperability solutions, united interfaces and model formats for transferring digital models, standards for exchange of manufacturing information and eventually IT-OT convergence
- Modelling of virtual Enterprise ***(related to topic b)***
  This includes multi-level heterogeneous modelling of virtual enterprises, novel risk analysis algorithms embedded in software services accessible to non-expert users and simulating tools for new process design

[2] Road4FAME Research Recommendations

- Distributed algorithms to process data in real time; algorithms for streaming data continuously to calculate results; manufacturing data-orientated search engine ***(related to topic a)***
- Visualization tools for contextual awareness ***(related to topic a)***
- Decision support tools ***(related to topic b)***
- Multilevel architecture models and model management including stochastic/human modelling and model integration i.e. ontology-based information modelling ***(related to topic c)***
- Collaboration model definition: protocols and regulations ***(related to topic b)***
- Exploitation of future internet architectures (***related to topic c)***
- ICT security and solutions for security on distributed/cloud systems ***(related to topic b)***
- IP protection
- Development of lower power electronics and communication protocols ***(related to topic a)***
- Development of very low cost sensors and their physical integration into smart systems and distributed controllers ***(related to topic a)***

Moreover, the Road4FAME results and recommendations are in good coherence with documents like the EFFRA roadmap, Smart industry roadmap, McKinsey report (McKinsey & Company, 2012 – [16]) and HVM report (Technology Strategy Board, 2012- [17]).

[3] EFFRA Roadmap

The Road4FAME road map addresses all domains of the EFFRA Roadmap, with 64 topics identified as clearly represented. There are particular synergies with Domains 2, 3, 4, 5 and 6.

- Advanced manufacturing processes (7/17 topics)
- Adaptive and smart manufacturing processes (17/17 topics)
- Digital, Virtual and Resource efficient factories (13/14 topics)

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[16] http://www.mckinsey.com/insights/manufacturing/the_future_of_manufacturing
[17] „A landscape for the future of high value manufacturing in the UK", TSB (2012) - https://www.innovateuk.org/documents/1524978/1814792/A+landscape+for+the+future+of+high+value+manufacturing+in+the+UK/0ffe7684-2f8c-4038-89b3-290c1085389d

- Collaborative and Mobile Enterprises (7/8 topics)
- Human Centric Manufacturing (8/11 topics)
- Customer Focused Manufacturing (12/12 topics)

[4] Smart Industry Roadmap

The Road4FAME road map clearly addresses topics in all the key areas identified in the Dutch Smart Industry road map as shown below:

- New Business with Smart Industry
- New Knowledge with Impacts for Smart Industry
- New Business Models (data) Networks Chain Organization and Logistics
- Integrated Knowledge
- New Skills for Smart Industry
- Supporting Policies for Smart Industry

[5] High-Value Manufacturing (HMV)

Recent work in the UK [5] has identified the most important high value manufacturing needs in order for the UK manufacturing industry to remain competitive. It also prioritise the necessary processes, products and service technologies necessary to support these needs. These are shown in the table below:

UK HVM Needs	UK HVM required processes, and service technologies	UK HVM required product, and service technologies
new production processes for scale and economy	additive manufacturing	materials and materials
design and manufacture for light-weighting	net shape manufacturing	science (excluding composites)
flexible and responsive manufacturing	robotics and automation customisation	low carbon technologies
intelligent systems	small run technologies (including distributed manufacture and 'batch size of one')	lightweight materials
data processing and storage	micro and nano-manufacturing processes	ICT and enabling ICT structures
new composites	end of life activities: recycling, re-use, renewing and re-lifting	biomaterials
alternative, bio-based sources for existing	surface engineering (finishing and coating processes)	sensor technologies
products and process materials	link design and manufacturing more closely	integrated technologies
systems modelling and simulation (including prototyping)	integrating technologies and processes	nanotechnologies
new power sources	bioprocessing for new/replacement materials/fuels	energy storage
organic materials for	ICT and enabling ICT structures	hydrogen fuel cells

electronics applications		
new high performance materials		robots
improved, integrated system design		integrated products and services
characteristics and modelling of new materials		new composites
products from waste and virgin biomass		nanomaterials
through-life engineering		

[6] McKinsey and UK-MVM-Report

There have been a few international and national studies on the importance of manufacturing to economic growth and resilience and to innovation adoption and diffusion. The following table compared the findings of two recent reports; one international from McKinsey's [4] and one national from the UK [5] on the Trends and Drivers (including national needs) and innovations that are important for future manufacturing.

Overall, there is very good agreement between the two reports as shown from the two comparison tables below. Regarding trends, drivers and needs there is excellent alignment between the two studies. Regarding innovations, the international report details more the ICT innovations important for future manufacturing while the national report provides more information in new materials and production process innovations probably reflecting key national competencies.

Categories	Trends , Drivers and Needs	
	McKinsey Report [5]	UK HVM Report [4]
	Trends and Drivers	Trends and Drivers / Needs
Demand	Shift of global demand towards developing economies	Economic power and opportunity continue moving east and beyond, but increasing transport costs encourage re-patriation / on-shoring
	Proliferation of products to meet fragmenting customer demand and need for customization	Flexible and responsive manufacturing
	Growing importance of value-added services & service business models	
	Rising wages in low-cost locations	Affluence increasing the pace of change
Supply factors	Shift in relative labor costs	
	Talent shortage	Ageing UK workforce skill shortages with low mobility
	Commodity price changes	
	Energy and transport costs	Increasing cost and scarcity of energy, resources and materials
		New power sources
Policy & regula	Support for domestic manufacturing	Evolving government policy, tax and regulations to maximise competitiveness
	Safety, quality and sustainability regulation	

	Intellectual property protection	
	Corporate tax rates	
Technology & Innovation		Supporting R&D and innovation remains a government priority
	New materials	New composites
		Organic materials for electronics applications
		New high performance materials
		Characteristics and modelling of new materials
	Product design	Design and manufacture for light-weighting
		Products and process materials
		Systems modelling and simulation (including prototyping)
		Improved, integrated system design
		Products from waste and virgin biomass
	Technology in production processes	Rising 'digital economy' and impact on 'traditional' products, processes and services as well as creation of 'new' demands
		New production processes for scale and economy
		Intelligent systems
		Data processing and storage
		Alternative, bio-based sources for existing products and process materials
	Business models	Through-life engineering
Risks & uncertainty	Demand volatilty	
	Commodity price volatility	
	Currency fluctuations	
	Supply-chain risks	Declining UK-based supply chain and increasing threats to SME from combination of skills and finance shortage, together with global OEM procurement policies
	Location-specific risks	Producing in UK incurs high cost of factors of production
	Capital cost uncertainty	Accessing credit and funding (including VC) and political impact on policy timeframes
Other		Growing, ageing population increases demand, waste and imposes challenges for health, social care and food
		Emerging new industries (eg, photonics, renewable energy) with strategic opportunities for global leadership by UK businesses, particularly in multi disciplinary areas

Categories	McKinsey Report [5]	UK HVM Report [4]
	Innovations	**Processes, and service technologies/ Product, and service technologies**
Innovation in materials	New materials, especially lightweight materials (i.e. carbon fibre etc)	Materials and materials science (excluding composites)
		Lightweight materials
		New composites
	Nanomaterials and Nanotechnology	Nanomaterials
	Biotechnology and biological agents	Biomaterials
	Recovering and recycling materials used in finished products	Low carbon technologies
Innovation in product design	Megatronics	
	Additions of computer intelligence (sensors , on-board computers)	Integrated products and services
		Integration of electronics into product and materials design.
		Nanotechnologies
		Energy storage
Innovation in production processes	Digital modeling, simulation and visualisation	Systems modelling and simulation tools, integrated system design, simulation and validation.
		Virtual prototyping, materials models, functionality and design.
		System integration of high complexity products.
	Advanced industrial robotics	Robotics and automation customisation: Process automation and human machine interface.
		Autonomy applications, particularly in production and servicing
	Additive manufacturing including 3D printing	Additive manufacturing
		Net shape manufacturing
	Green manufacturing	
		Small run technologies (including distributed manufacture and 'batch size of one')
		Micro and nano-manufacturing processes
		Surface engineering (finishing and coating processes)
		Link design and manufacturing more closely
		Integrating technologies and processes
		Bioprocessing for new/replacement materials/fuels
Innovation in manufacturing Information		ICT and enabling ICT structures: Ability to integrate new and existing processes and systems in a customisable manner(including ICT)
		Integrated technologies
	Product design databases to enable	

	concurrent engineering, rapid experimentation, simulation and co-operation	
	Aggregate and share customer data to improve services, increase sales and enable design-to-value	
	Source and share demand forecasting and supply planning across suppliers and use external variables	
	Implement lean manufacturing; model and optimize production; develop dashboards	
	Implement sensor data-driven analytics to improve throughput and enable mass customization	Sensor technologies
		Intelligent systems and embedded electronics: Robust 'live' data capture and comprehensive capture and use of product/process information. New sensor/NDT devices and smart and multi-functional components which are embedded and/or intelligent.
		Large area, printable, cheap electronics, integrated with other manufacturing processes for energy management, security, packaging and light weighting.
	Collect real-time after-sales data from sensors and customer feedback to trigger services and detect flaws	
	Improve supply chain visibility through control towers and organisation-wide collaboration	
	Use of data gathering sensors in production machinery and in logistics	
Innovation in manufacturing business models	Mass customization	
	Circular economy	End of life activities: recycling, re-use, renewing and re-lifing
	Frugal innovation	
		'Plug and play' manufacturing: Application of modularity to develop a high volume production environment, where the production units can be combined in a flexible manner and serviced more effectively.
Other		Hydrogen fuel cells
		Robots