



5G and the Factories of the Future

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Executive summary

The European manufacturing sector has changed profoundly over the last years. Europe has engaged in a steady re-industrialisation of the sector, strongly leveraging ICT enhancements, since off-shoring of production to low wage countries is neither a sustainable business strategy nor a sound source of wealth and job creation in Europe. Meanwhile, a fourth industrial revolution has started, which is fuelled by cyber-physical-systems (CPS) and Internet-of-Things (IoT) technology, to realize highly efficient, connected and flexible Factories-of-the-Future.

Fundamental to the fourth industrial revolution is the implementation of a reliable communication layer capable of dealing with an increase in several orders of magnitude the number of assets, volume, variety of information and reaction times in future manufacturing systems.

5G promises to be a key enabler for Factories of the Future. It will not only deliver an evolution of mobile broadband networks, it will provide the unified communication platform needed to disrupt with new business models and to overcome the shortcomings of current communication technologies. As such, 5G technologies have the potential to amplify and accelerate the ongoing transformation, and to unlock a next level of efficiency gains in manufacturing even for the vast community of European manufacturing SME.

Two main trends in manufacturing are driving this transformation and will influence the future competitiveness: (1) the increasing role of services in manufacturing and (2) the growing importance of global value chains. It is estimated that by 2025 manufacturers will get more revenue from services than from products. This is a consequence of a trend called “servitization of manufacturing”, indicating a shift from solely selling produced goods to providing added value services together with either connected (smart) or non-connected goods. The growing importance of global value chains is a second trend that drives the demand for truly connected manufacturing eco-systems.

Five use case families have been identified that each represent a different subset of stringent requirements along supply chain and manufacturing networks:

- *Time-critical process optimization inside factory* to support zero-defect manufacturing, increased efficiencies, worker satisfaction and safety, leveraging the integration of massive sensing technologies including 3D scanning technologies, adoption of wearables, and collaborative robots in closed-loop control systems. This use case family is characterized by communication latencies that may go below 1ms.
- *Non time-critical optimizations inside factory* to realize increased flexibility and eco-sustainability, and to increase operational efficiency e.g. through minimal stock levels. Given the harsh and metalized industrial environments, indoor coverage and high availability are key requirements.
- *Remote maintenance and control* optimizing the cost of operation while increasing uptime. This use case family involves the integration of 3D virtual reality, and will require increased capacity to facilitate video-supported remote maintenance, from any place in the world.
- *Seamless intra-/inter-enterprise communication*, allowing the monitoring of assets distributed in larger areas, the efficient coordination of cross value chain activities and the optimization of logistic flows. To support these use case, there is a specific need for flexible, reliable and seamless connectivity across different access technologies, as well as the support for mobility.



- *Connected goods*, to facilitate the creation of new value added services and the optimization computer aided design driven by real-time data, collected during the complete lifetime of a product. There is the need for ultra-low-power (high autonomy), and ultra-low-cost communication platforms.

Considering the different use case families, it becomes clear that the manufacturing industry is one of the most demanding verticals with respect to ultra-low latencies, ultra-high availability, reliable indoor coverage in harsh environments and energy-efficient and ultra-low communication costs for produced, connected goods. Current technologies lack capabilities with respect to the wireless performance, managing heterogeneity, security and trust, leveraging Internet technologies, and flexible network and service management.

Regarding the 5G roadmap and future research, we therefore recommend focussing on:

- high throughput with research on ultra-reliable wireless deterministic communication
- high availability with research on proper security mechanisms and ubiquitous coverage and device to device traffic/service offloading mechanisms
- lowering the TCO with research on network capabilities to manage heterogeneity
- high flexibility with research on plug-and-produce capabilities by adopting internet technologies into industrial stacks
- new data-driven business models for SMEs and large companies, exploiting data-oriented services and network virtualization concepts
- changes needed with respect to legislative framework, standards and social acceptance
- building a specific strategy for 5G and manufacturing SMEs

Joined research by Europe's 5G and manufacturing community is the key for world-leading innovations and for increased competitiveness in the domain of Factories of the Future. It is the fundamental promise of 5G technologies to enable new business engagement models, and to accelerate the adoption of next-generation, digital platforms needed to realize highly efficient and flexible Factories of the Future.



1. Socio-economic drivers of the Factories of the Future initiative in Horizon 2020

The European manufacturing sector has suffered from increased competition of BRIC countries and the effects of financial crisis, which in 2012 triggered the European Commission to call for immediate action to implement a Factories-of-the-Future (FoF) PPP (Public Private Partnership) to increase **Industry's share of GDP to 20% by 2020**. The terms "Smart Manufacturing", "Intelligent Plants" and "Factory of the Future" all refer to the vision on how manufacturing processes will be operated in the future. While the introduction of steam power, the assembly line and early automation characterized the first three industrial revolutions, a fourth revolution is ongoing and fuelled by Cyber-Physical-Systems (CPS) as the basis of **intelligently connected production information systems** that operate well beyond the physical boundaries of the factory premises. A wireless, broadband, global, reliable network with mobile support is the basis for operation of CPS in the factories of the future.

A digital transformation of European manufacturing processes both for large industries but in particular for SMEs is key to achieving the GDP share objective¹. The expectation is for radical disruptive changes across the product life cycle in logistics, product design, shop-floor automation and customer relationship management. This is a foundation for development of new services around the products and the evolution of value chains into dynamic and flexible value networks of connected enterprises.

EU wide strategy for the digitisation of European industry in order to *"ensure that all industrial sectors make the best use of new technologies and manage their transition towards higher value digitised products and processes"*², has been formulated recently and relies on four interlinked lines of actions³:

- **Digital innovation hubs** accessible for any business in Europe to facilitate access to digital technologies and expertise in support of digital transformation,
- Leadership in next generation **open and interoperable digital platforms**,
- Preparing our **workforce for digital opportunities** and
- Digitally fit-for-purpose **regulation**.

5G technologies have the potential to bring major opportunities for the support and global operation of **next generation of digital platforms driving factories of the future operation**, embedding CPS in machines, vehicles, infrastructure, etc. This section is structured highlighting the different drivers for the European industrial digitisation and product servitization:

- **Economic drivers** for EU re-industrialisation,
- **Socio-economic** FoF mega-trends & **Key transformations** in manufacturing,
- The **global race** to set CPPS standards.

¹ ICT Innovation 4 Manufacturing SMEs (I4MS): Enhancing the digital transformation of the European manufacturing sector. http://i4ms.eu/documents/i4ms_v11.pdf

² Europe's future is digital. Speech by Commissioner Oettinger at Hannover Messe http://europa.eu/rapid/press-release_SPEECH-15-4772_en.htm

³ Digitising european industry", Brussels, 30 June 2015, European Commission, DG Connect, Components and systems http://ec.europa.eu/newsroom/dae/itemdetail.cfm?item_id=24190&newsletter_id=0&lang=en

Manufacturing in EU: Economic drivers for re-industrialisation

The manufacturing sector is a pivotal driver for growth of the economy. In fact it accounted in the period 2010-2012 for about 60% of productivity growth and 67% of exports in Europe. On a global scale, the manufacturing sector represents 16% of the global GDP employing close to 45 million persons in advanced economies. According to McKinsey⁴, 30% to 55% of the activity in manufacturing is related to ICT intensive services and out of every dollar invested in manufacturing infrastructure 19 cents go to ICT services. Cyber Physical System (CPS) innovations that could find direct application in vertical sectors are currently accounting for more than \$32.3 trillion in economic activity, and with the potential to grow to \$82 trillion of output by 2025—about one half of the global economy.

Europe has engaged in a steady re-industrialisation with a strong ICT contribution (digital manufacturing) to reach the 20% GDP contribution towards 2020. However, a recent study from the think tank “Observatory on Europe 2014”, initiated by The European House – Ambrosetti⁵, suggests that the contribution of “traditional” manufacturing activities alone to the value creation will not suffice to reach the target. Service related activities will have a prominent role in the value creation. Services will also play a key role to secure job creation in manufacturing. This trend is known as the “SMILE” effect and it is estimated that by 2025 manufacturers will get more revenue from services than from products⁶. This is a consequence of a trend called “servitization of manufacturing”, indicating a shift from solely selling produced goods to providing added value services together with either connected (smart) or non-connected goods. Regarding connected goods, Oxford Economics predicts that by 2016, 53% of manufacturers will offer such “Smart Products”⁷.

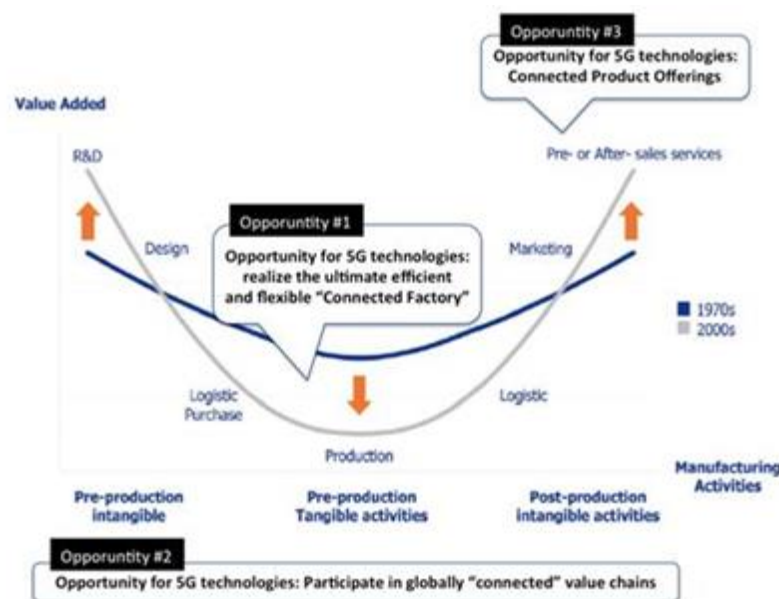


Figure 1: Opportunities for 5G mapped to the SMILE-distribution of value added per manufacturing activity – Elaboration on The European House – Ambrosetti, Bruegel and OECD, 2014

⁴ *Manufacturing of the future, The next era of global growth and innovation*, McKinsey Global Institute, Nov. 2012.

⁵ Valerio De Molli, Managing Director, The European House – Ambrosetti, Italy – “*European Manufacturing Between Structural Trends and Future Perspectives: Taking up the Challenge*”, Industrial Policies for Global Manufacturing, World Manufacturing Forum, 2014, Milano, 1-4 July, 2014.

⁶ Road4Fame: *Development of a Strategic Research and Innovation Roadmap for Future Architectures and Services for Manufacturing in Europe*. <http://road4fame.eu/>

⁷ *Smart, Connected Products Manufacturing's Next Transformation*, Oxford Economics, 2013.



The progressive “**servitisation**” of manufacturing and the growing importance of **Global Value Chains** (GVCs) and **CPS production** have associated a demand for increased connectivity and information/data exchange across a larger, more diverse set of stakeholders, new scales and new response times. Therefore, there is the opportunity for 5G technologies to contribute to cost-effective and reliable support, in order to:

- realize the ultimate concept of an efficient and flexible “**Connected Factory**”.
- participate in globally and highly automated “**Connected Value Chains**”, at competitive costs, for both low- and high-data rate use cases.
- bring machine-type-communications to a new level across the complete product life cycle and fully embrace the “**Connected Products**” paradigm.

Socio-economic megatrends and key transformations in manufacturing

The manufacturing sector re-industrialisation is being carried out under clear socio-economic megatrends, which have a direct bearing on European manufacturing⁸. These megatrends are:

- changing **demographics** (growing world population, ageing societies, increasing urbanisation),
- globalisation and future **markets** (BRIC and beyond),
- scarcity of **resources** (energy, water, other commodities),
- the challenge of **climate** change (increasing CO₂, global warming, ecosystem at risk),
- dynamic **technology** and innovation (ICT and virtualisation, internet-of-things, technology diffusion, the age of life science, ubiquitous connectivity, sensing and digitalisation),
- global **knowledge** society (know-how base, gender gap, war for talent, multiplication of data and information),
- mass **customisation** (personalised customisation),
- **sharing** global responsibility (shift to global cooperation, growing power of NGOs, increasing philanthropy).

To cope with this socio-economic megatrends and a better integration of smart factories within hyper-connected smart societies and cities, the Factories of the Future research roadmap is focused on the development of innovative technologies (including ICT) that will allow

- reconfigurable, adaptive and evolving factories capable of small-scale production,
- high performance production combining flexibility, productivity, precision and zero defect while remaining energy and resource efficient,
- safe and attractive workplaces,
- reduce the consumption of energy and water,
- near-to-zero emissions including noise and vibration.

Following the European Factories-of-the-Future Research Association (EFFRA) the digitalisation of business processes (design, planning, ramp-up, production, maintenance and end-of-use) can be classified under one of the categories below. However, all categories inherently rely on the effective interconnection of machinery, robots, lines, products, sensors and operators to each other and to back-end systems, which should be a main driver for 5G network business case.

⁸ Factories of the Future Multi-Annual Roadmap For The Contractual PPP under Horizon 2020
http://www.effra.eu/index.php?option=com_content&view=category&layout=blog&id=85&Itemid=133



- **Smart Factories:** Related to automated operation of the shop-floor, integrated embedded computers, real-time monitoring, adaptive control, autonomous actuation and cooperative machine to machine interaction.
- **Digital Factories:** Related to human-team agile exploitation/analysis of vast amounts of digital information, knowledge management, informed planning and complex simulation and collaborative product-service engineering support.
- **Virtual Factories:** Related to connected and collaborative enterprises and highly flexible global supply chains of connected eco-systems.

Through the implementation of smart, digital and virtual business processes, the ambition by 2020 is to leverage **sustainable 100% available factories**. CPPS will have to deal with key production process monitoring & control operations that will expand from the actual manufacturing process self-adjustment for zero defect, energy neutral manufacturing to the actual support for process optimization based on informed decision making by the production engineers (better planning of maintenance operations, early warning of process drifts, event and alert management, etc.). The **timely flow of information among devices and among devices and humans is of key importance** to ensure the digital consistency of data, the proper synchronisation of digital manufacturing processes (e.g. simulation) with the physical counterpart (e.g. machine operation).

A key aspect of the 2020s will be the so called “energy transition”. Indeed, major countries will take ambitious commitments in terms of carbon emission reduction during COP21. Manufacturing needs to decrease energy consumption in all domains. It means that **ICT for manufacturing, including the 5G contribution to the energy budget, should be at a minimum**. All low-power access technologies will be very welcome and that the 5G KPI to divide the energy consumption of communication networks by 10 for the same amount of traffic will be very important for manufacturing. More than that, the possibility to have deep sleep modes for inactive machines and fast wake ups is another key 5G use case for factories of the future. Most of the above megatrends also hold for 5G technologies, and by extension to the ICT sector in general. It is in the roadmap of 5G to:

- facilitate **automation**, which means for manufacturing to facilitate mass customization, efficiency optimization, global value chain communication, knowledge sharing, etc.,
- address **ubiquitous communication** for the growing world population, in both dense urban areas and less covered rural areas. In relation to manufacturing, this translates for example to industrial areas with dense machine-communications, as well as to coverage of rural areas to monitor usage of produced goods,
- contribute to **wide-area resource monitoring networks** to optimize the usage of scarce resources,
- **minimize energy consumption** of the ICT sector, including the ICT applications for the manufacturing industry.

A global race to set industry standards

Another main transformation in the manufacturing industry involves the industry-driven alliances that together try to accelerate the introduction of new technologies by the introduction of industry standards. Among those the most important in Europe is called „Industry 4.0”, stated as the 4th industrial revolution by the German Industry 4.0 Platform⁹ which was established as a joint

⁹ Industry 4.0 Platform: <http://www.plattform-i40.de/>

collaboration between major public and private initiatives. The German movement is now embraced by many *Vanguard*¹⁰ countries and regions in the EU - see **EU Workshop on European Co-operation on Innovation Digital Manufacturing**¹¹. The Advanced Manufacturing & Smart Manufacturing Leadership Coalition in the US or the Intelligent Manufacturing in China, helped to establish the **Industrial Internet Consortium (IIC)** in US and to define a "**Made in China 2025**"¹² strategy during the opening of China's annual session of the National People's Congress in Beijing on March 5, 2015, driven by the Premier Li Keqiang. Worldwide co-operation is however ongoing and pursues converging standards, or at least converging reference architectures. The China-EU cooperation meeting in the field of Industry Internet of Things held on July 6 2015¹³ provided clear examples of how to converge, which coincide with the announcement on July 4, 2015 by the **Chinese Government** about the "**Internet Plus**"¹⁴ action plan, aimed at integrating the Internet with traditional industries and fuel economic growth. The "Internet Plus"¹⁴ action plan intends to seek innovation driven development, apply smart technologies, integrate mobile Internet, cloud computing, big data and the IoT with modern manufacturing, and to upgrade China from a manufacturer of quantity to one of quality. Moreover, both the IIC¹⁵ and the Industry 4.0 initiatives have recently made strong efforts to provide a standardised Reference Architectural Model (RAMI 4.0)¹⁶, which is linked to international standards IEC 62890, ISO/IEC 62264 (hierarchical arrangement of enterprise domains and automation system integration framework) and IEC 61512. The models are still too recent to allow for global convergence.

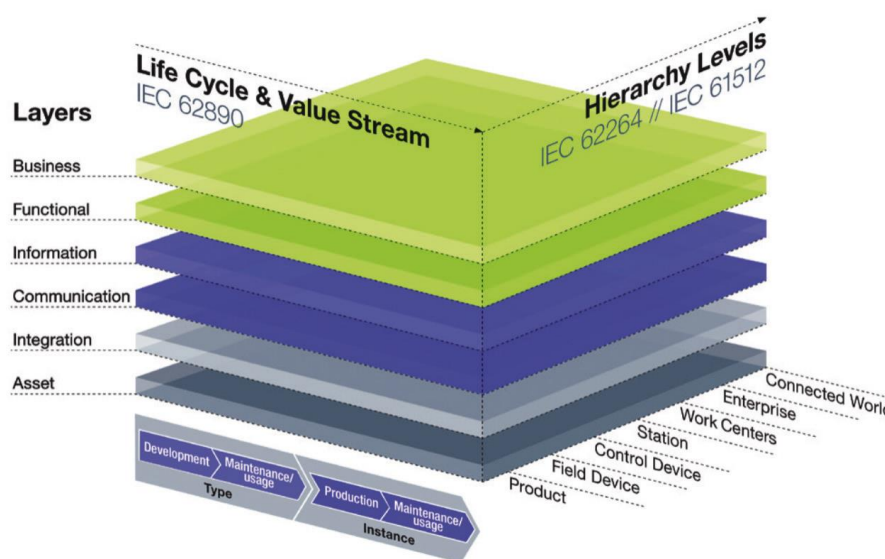


Figure 2: RAMI 4.0 reference architecture – July 2015

¹⁰ <http://www.s3vanguardinitiative.eu/>

¹¹ H. Thompson, P. Kennedy, O. Lazaro, H. Egner (Rapporteurs) "European Co-operation on innovation in digital manufacturing, Brussels, 21-22 January 2015". <https://ec.europa.eu/digital-agenda/en/news/european-co-operation-innovation-digital-manufacturing>

¹² http://www.gov.cn/zhengce/content/2015-05/19/content_9784.htm;

http://english.gov.cn/policies/latest_releases/2015/05/19/content_281475110703534.htm

¹³ http://euchina-ict.eu/wp-content/uploads/2015/08/CHOICE_Workshop_on_Industry_IoT_Event-report.pdf

¹⁴ http://www.gov.cn/zhengce/content/2015-07/04/content_10002.htm;

http://english.gov.cn/policies/latest_releases/2015/07/04/content_281475140165588.htm

¹⁵ <http://www.iiconsortium.org/IIRA-1-7-ajs.pdf> - Industrial Internet Consortium Reference Architecture, June 2015.

¹⁶ ZVEI RAMI 4.0 reference architecture, – July 2015

<http://www.zvei.org/Downloads/Automation/5305%20Publikation%20GMA%20Status%20Report%20ZVEI%20Reference%20Architecture%20Model.pdf>

2. How 5G can be a catalyser for Factories of the Future

Technical catalysers for Factory-of-the-Future

Factories of the Future leverage the technical integration of “Cyber-Physical-Systems” (CPS)¹⁷ in production and logistics as well as the application of “Internet of Things and Services” (IOTS) in industrial processes. The figure below illustrates the interplay of technological innovations in manufacturing with the latest ICT-related technologies. Robots, 3D-printing, advanced materials, novel sensors, autonomous vehicles, etc. all contribute individually to increased efficiency and flexibility. Part of the increased efficiency and flexibility, can be realized by connecting and integrating these technologies in a smart and manageable manner and extracting actionable insights. IoT technology, cloud solutions, big data crunchers, and cyber security components are key ingredients for this digitalization. 5G technologies can play a key enabling role in integrating these ingredients and offering a ubiquitous platform to interconnect machines, robots, processes, auto guided vehicles, goods, remote workers, etc.

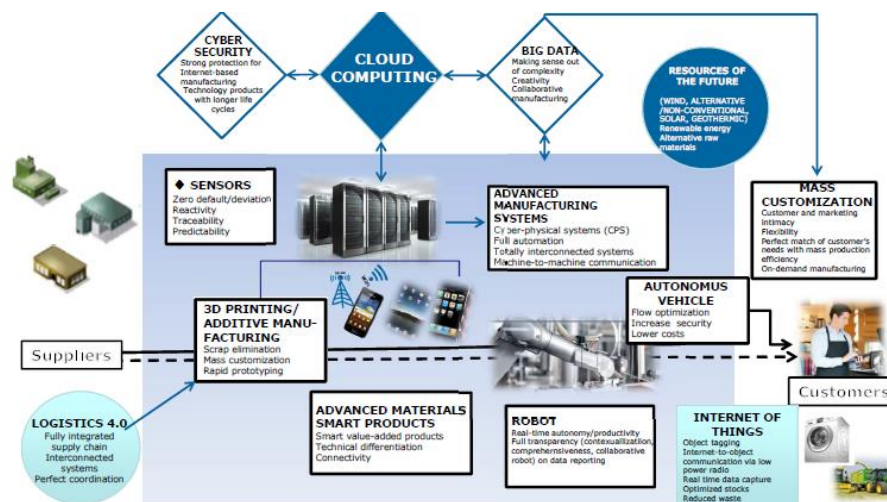


Figure 3: What is Industry 4.0 (Source: Roland Berger, Think Act Industrie 4.0)

5G as key technology platform for manufacturing

The combination of the above mentioned trends and technologies is the basis for the conceptualization, production and exploitation of new innovative offerings and business models creating a disruptive effect in the manufacturer market. Manufacturers need to redesign not only their value proposition, but also their business model and organization. This transformation requires the building of new capabilities in many areas such as: value network, processes, product performance, user experience, financial, management, etc. Together with these new capabilities, the company needs to transform its organizational design in three main domains:

- In the "horizontal integration" domain

¹⁷ Manufacturing industry is looking at Cyber Physical Production Systems (CPPS) as the next industrial revolution. Cyber-Physical Production System (CPPS) vision is related to Systems of Physical Objects and corresponding Virtual (Digital) Objects that Communicate via omnipresent information networks – Cassina J. et. al. “Pathfinder Roadmap White Paper”, July 2014 http://www.pathfinderproject.eu/downloads/results/Pathfinder_WhitePaper1.pdf



- In the “vertical integration” domain:
- In the “End-to-End Integration” domain.

In addition, it also requires the tight integration among these three domains, the horizontal, the vertical and the circular. 5G is a key technology to enable this transformation.

5G as key technology platform for new value chains (horizontal integration)

From suppliers to business partners. By horizontal integration domain we mean the inter-industry value chains and supply chains, starting from raw materials and ending with the finished products delivered to customers. Smartization and servitization aspects can be now implemented in any good such as locks, smart meters, smart lights, lifts, vehicles, machine tools and in any product that one can imagine. This has great impact not only in how these products are designed, manufactured, sold and maintained, but also in who are the providers, with the appearance of new players and the disappearing of others, but, moreover, in a closer relation with the clients. The transformation to become a provider of an integrated product-service offering requires a greater degree of cooperation between providers and the supporting network. We can observe this proposition in the smartphone industry. Successful key players of the smartphone industry were able to build such tight cooperation with content providers, financial, media, entertainment ..., introducing new supplier actors quite different from the usual ones, creating a rich service (e-service) ecosystem over the original product and multiplying innovation and business sources.

5G as key technology platform for networked factories (vertical integration)

From productivity efficiency to increased added value. By vertical integration domain we mean the linkage of production processes performed by multiple systems inside the manufacturer boundaries. Whereas the pure physical product logic relies on optimal and efficient industrial processes, a product-service system requires the redesign of the manufacturing infrastructures and context to cope with the full integration of services in the production process. For instance, new personalized user demands could be properly matched with new services designed and provided after the physical product has not only been manufactured but also delivered to the customer. This requires a new approach for the manufacturer infrastructure.

5G as key technology platform for the full product life-cycle (end-to-end integration)

From product performance to user engagement. By end-to-end integration domain we mean the integration throughout the full lifecycle process so that the product and service part of the business proposition are conceived, designed, built, delivered and disposal. The provision of product-service systems allows for a stronger connection with the client or user: inputs from the client as well as their feedback are obtained in a different way (habits capturing, training, e-concepts tests, user communities ...). One of the key aspects of moving from a product-centric organization to a product-service-centric one is the way the customer relationship changes from a simple transaction to a long term relationship through a broad offer of services supported by a network infrastructure. Through smartization and servitization, and supported by a network infrastructure, manufacturers can learn about the way users and companies are using their products. This can be a valuable input that manufacturers can use for the re-design of their products or for the generation of variations to the products. Usually, business innovation requires closing the gap with the final users of products.

Taking the factories to the next level of smart connected factory eco-systems, comes with new challenges to deliver an industrial internet that meets the stringent SLAs and requirements. We discuss the requirements in section 3 and missing requirements in section 4.

The manufacturing industries require support from the 5G community, in particular for:

- highly reliable wireless communication to integrate mobile robots, AGVs, etc. into the closed loop control processes
- a seamless experience while using hybrid wireless and wired network technologies the cost-effective management of the network that unifies the connected assets of a factory
- innovations inside the network to offer networked services

5G technologies will play a key role as unifying platform that supports all communication scenarios, and offers mobility-features and seamless service experience. This role of 5G technologies very well corresponds with the 5G objective to integrate networking, computing and storage resources into one programmable and unified infrastructure. This unification will allow for an optimized and more dynamic usage of all distributed resources, and the convergence of fixed, mobile and broadcast services. The envisioned 5G platform will need to link wireless access with wired industrial ethernet and will include also components like edge computing, cloud, local gateways, big data and analytics, IoT management, etc. Furthermore, the boundary between wide-, local- and personal-area networks is getting more blurred, calling for a seamless interaction between those domains.

Manufacturing use cases: five use case families

With respect to manufacturing, five use case families have been identified to illustrate the requirements along supply chain and manufacturing networks for realizing the next generation connected factory. We consider processes within the walls of any factory, but also processes between different factory buildings, such as logistics. The boundaries between what is internal to the factory and what is external to the factory are more and more blurring with innovative concepts such as virtual plants. Factories of the future are indeed not stand alone closed entities, but will be a part of a larger value chain and ecosystem. The table below shows the 5 use case families, illustrated with representative scenarios, and highlights the potential impact on manufacturing.

	Use case FAMILY	Representative SCENARIOS	Dominant IMPACT
Use case family 1	Time-critical process optimization inside factory	Real-time closed loop communication between machines to increase efficiency and flexibility.	Increased efficiency Increased worker satisfaction Increased safety/security
		3D augmented reality applications for training and maintenance	
		3D video-driven interaction between collaborative robots and humans	
Use case family 2	Non time-critical in-factory communication	Identification/tracing of objects/goods inside the factory	Increased efficiency Increased flexibility Minimized stock levels Increased eco-sustainability (emissions, vibrations, noise)
		Non-real-time sensor data capturing for process optimization	
		Data capturing for design, simulation and forecasting of new products and production processes	

Use case family 3	Remote control	Remote quality inspection/diagnostics	Increased product/process quality
		Remote virtual back office	
Use case family 4	Intra-/Inter-Enterprise Communication	Identification/Tracking of goods in the end-to-end value chain	Increased efficiency (cost, time)
		Reliable and secure interconnection of premises (intra-/inter-enterprise)	
		Exchanging data for simulation/design purposes	
Use case family 5	Connected goods	Connecting goods during product lifetime to monitor product characteristics, sense its surrounding context, and offering new data-driven services	Increasing sales (new products, services) Improved product/process design

Table 1: Five use case families for manufacturing and their business impact

Use Case Family 1 (UC1): time-critical, reliable process optimization inside digital factory

To increase the efficiency of production lines, there is a trend of instant optimization based on real-time monitoring of the performance of sub-components, the measured quality variations of produced goods, the interactions by operators and changing factors in the environment. Some of the sensors may communicate at low-bitrates but with ultra-low latency and ultra-high reliability, whereas vision-controlled robot arms or mobile robots may require reliable high-bandwidth communication. Apart from machine-type communications, new scenarios for time-critical communication are emerging with the collaborative functions offered by a new **generation of robots**, the introduction of wearables on the shop floor, and the evolutions with respect to augmented reality. An increasing number of devices becomes wireless and mobile, and demand **the transfer of “heavy” data** (3D models, large historic data sets, etc...) for fast intervention, maintenance or assembly tasks. The amount of information to share and use, to make on-the-spot decisions in a collaborative manner, is significant.

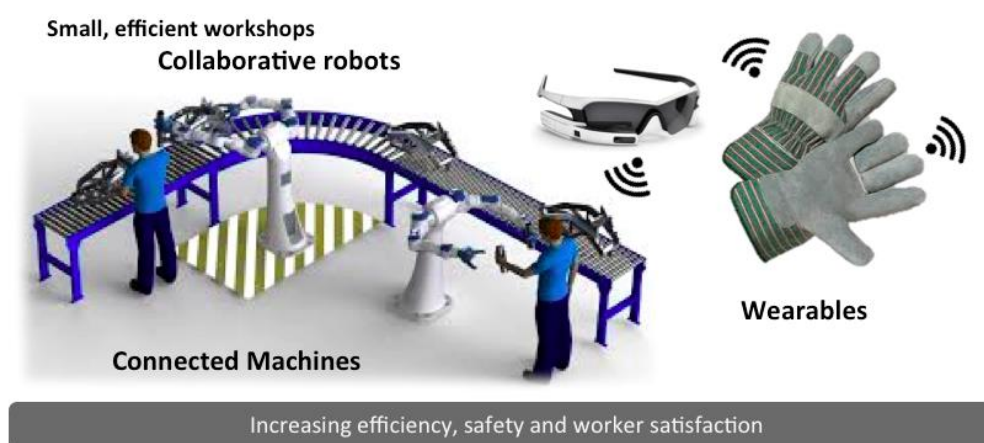


Figure 4: Use case family 1 – Time-critical process optimization inside factory

The collaboration takes place in real-time with the robot adapting to operators' faculties when interacting with the operator's wearables, the surrounding sensors and the machine control systems. Uncaged robots will facilitate further automation, augment the operator tasks efficiency, production

yield, quality output and increase the operator overall safety. The robotic collaborative operation is already defined in ISO 10218 standard, but with respect to ultra-fast and ultra-reliable access to moving objects, 5G can play a differentiating role. A flexible convergent and seamless connectivity offer across different radio access technologies will be required in order to adapt instantaneously variable capacity and mobility needs to changing environments.

Use Case Family 2 (UC2): non time-critical communication inside the digital factory

Whereas in Use Case Family 1 (UC1) the involved machines and robots are part of closed, time-critical control loops, this use case group considers less time-critical communications that involve the localization of assets and goods in on-site production and logistic processes, non-time critical quality control, or data capturing for later usage in virtual design contexts. Similarly, the communication with operators on the shop floor may not always require ultra-high latencies, given that human response times are much higher compared to machine-level response times.

With respect to logistics, accurate localization of forklifts, auto guided vehicles, trolleys, vessels, etc. can significantly decrease error rates in picking and packaging, by validating the source and destinations of picked goods or parts in real time with intelligent warehouse management systems (WMS). With such technology it can be avoided that e.g. products are moved into the wrong truck, and as such realize significant cost savings along the value chain.

The successful capturing of sensor data on the shop floor is another use case that requires less time-critical communication inside the factory. It is crucial to fuel the further digitization of the factory, and to facilitate virtualized design processes that integrate simulator data with real-life, data sensed during production. Successful combination of these data, will contribute to minimizing product lead times and to the design of superior products that can be produced with a minimal number of defects.



Figure 5: Use case family 2 – Non-time-critical in-factory communication

The challenge is to ensure high availability of the wireless networks, even in harsh industrial environments. Indoor coverage enabling the connectivity of complete locations (e.g. including all floors, all rooms, etc.) will be a key requirement to guarantee the full availability and reliability of future automated industry applications.

Use Case Family 3 (UC3): Remotely controlling digital factories

In UC1 and UC2 we consider local on-site communication within a particular plant. In this use case the public wireless access network also takes a role in the end-to-end communication between remote workers and the factory. The simplest set-up of this use case involves remote control applications running e.g. on tablets or smart phones. However, with the trend of new augmented

reality (AR) devices, new remote services may arise that facilitate the creation of virtual back office teams. These remote teams may use the data coming from smart devices for preventives analytics and easy access to work instructions, e.g. you see what the camera or iPad/Google Glass of a local worker sees. Additionally the application of augmented reality in the plant will facilitate:

- Augmented-reality support in production and assembly: Precisely positioned picture-in-picture fade-ins, it shows the operator the next step and helps avoiding misplacement and unnecessary scrap,
- Augmented-reality support in maintenance and repair: Repair machine without training due to augmented information and operational guidance.

Solutions for communities of practice will facilitate cross-functional communication, effective knowledge sharing and collaborative design platforms.



Figure 6: Use case family 3 – Remote maintenance and control

In this use case family, there is a less stringent need for low-latency. Interaction times up to seconds are acceptable in case of remotely servicing machines. However, high availability is key to ensure that (emergency) maintenance actions can take place immediately. In case of video-controlled maintenance, with real-time augmented content mixed into the video signal, bandwidth is important. Also latency becomes important in particular for real-time, remote motion control of local robots. Edge computing within the network is needed in order to fulfil the low latency requirements. Opening up the machines to allow remote reconfiguration also introduces new vulnerabilities with respect to malicious take-over of a machine or plant. Physical security measures, taken on-site, are in that case not sufficient anymore. The cyber-representation of a factory or supply chain therefore needs to be protected, with mission-critical actions being shielded for non-authorized parties.

Use Case Family 4 (UC4): Seamless intra-/inter-enterprise eco-system communication

In the new connected enterprise environment, the ambition is to 'Design anywhere, produce anywhere', to integrate and automate value chain processes, and to develop new business models.

Future communication solutions are expected to ensure the connectivity between different production sites as well as with further actors in the value chain (e.g. suppliers, logistics) seamlessly and in real time. Furthermore they should allow the monitoring of assets distributed in larger areas, the efficient coordination of cross value chain activities as well as the optimization of logistic flows.

Ubiquitous networking between all components and systems involved in the production chain distributed across many sites is a key issue in this context (see Figure below). 5G technologies will be needed to create those smart environments for the industry.

A high level of network and service availability and reliability including wireless link is one of the key requirements. In order to adapt instantaneously variable capacity and mobility needs to changing environments, flexible convergent and seamless connectivity across different access technologies (radio and fixed) will be required.

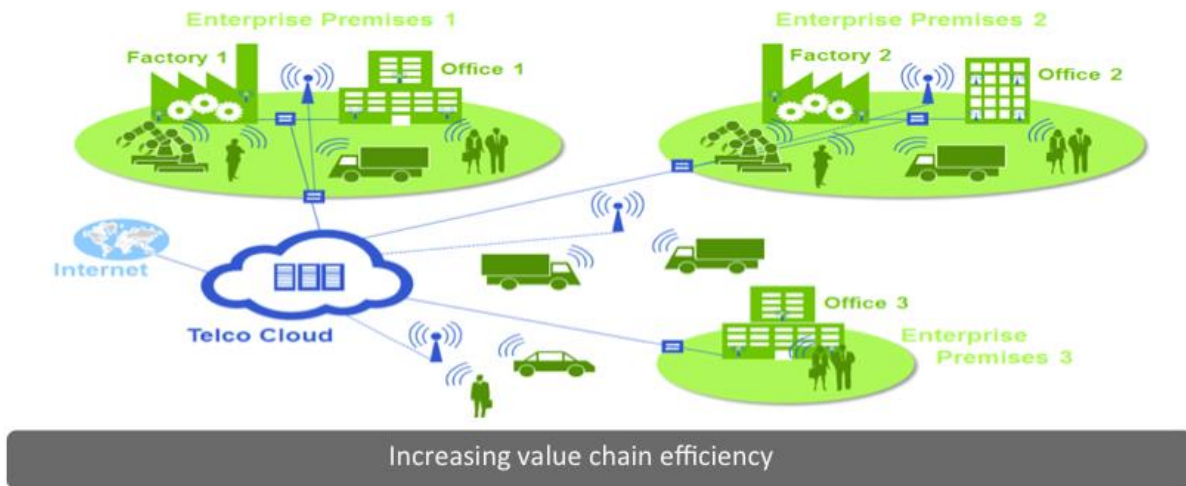


Figure 7: Use case family 4 – Intra-/Inter-Enterprise Communication

METIS D1.5: Industrial automation based on smart factory/manufacturing approach (interconnection of enterprise premises, integration of enterprise networks, ubiquitous access to all components, etc.).

Use Case Family 5 (UC5): Connected goods – incorporating product lifetime

The servitisation of physical goods will be of strategic importance for the manufacturing industry. Instead of selling machines and parts, proper monitoring of these assets will allow selling engine hours, selling km, selling drills, etc. These new business models require and exploit extensively product lifecycle data, combined with personalized usage and context data. By reinforcing this product-service relation, factories will evolve to a data-driven eco-system.

Factories will also play an important role in the provisioning of the connected goods that are produced. The ultimate vision is that produced goods remember how they were made, and augment this production-related data with usage-related data collected during the lifetime of the product. Cost-effective communication schemes are needed to accelerate these data collection scenarios. Smart data filtering and scalable data analytics will fuel a new way of data-driven, computer-aided design. Model-based optimization will become key in a world of virtualization, where simulation data can immediately be validated against real-life product data.



Figure 8: Use case family 5 – Connected goods

To realize the true value of connected goods, autonomy is a key requirement. The cost of replacing batteries is a main roadblock together with the cost of communication. New low-power, low-cost, long-range communication technologies need to be integrated in factory communication networks.

The table below summarizes the high level needs with respect to communication for each of the five use case families. With respect to the wireless channel, latency, reliability and bandwidth are considered. On infrastructure level, the assessment parameters are the ubiquitous availability (coverage), the need for security and the need to support heterogeneous devices and technologies. The autonomy of battery-powered sensors is another key requirement that may impact the design and implementation of the embedded communication modules.

		High level needs for the communication						
		Latency	Reliability	Bandwidth	Coverage Availability	Security	Heterogeneity	Autonomy
UC1	Time-critical optimization	Ultra-low	Ultra-high	Low to high	Indoor	Critical	Important	Less critical
UC2	Non-time critical control	Less critical	High	Low to high	Indoor + On-site outdoor	Critical	Important	Critical for location tracking
UC3	Remote control	Less critical	High	Low to high	Wide Area	Critical	Important	Less critical
UC4	Intra-/Inter-Enterprise Communication	Ultra-low to less critical	High	Low to high	Wide Area (on-site/ outdoor)	Critical	Important	Less critical
UC5	Connected Goods	Less critical	Low	Low	Wide Area	Important	Important	Critical

Table 2: High-level needs for communication for the five use case families

Considering the current evolution of technologies, UC1 and UC5 introduce the most novel challenges with respect to the seamless wireless integration.



- UC1:
In factories-of-the-future stringent requirements exist for indoor mission-critical process optimizations. Ultra-low latencies, combined with ultra-high reliability, in a heterogeneous environment require enhancements to the current 4G and planned 5G technology.
- UC5:
To deliver the virtual factory, exploiting product lifetime data from connected goods “living” in the wide area network, a new range of networking technologies is required that adheres to minimal energy consumption, ultra-high autonomy, low subscription costs, for lower bitrate communication. The frequency and latency of communication is less critical.

While UC2, UC3, UC4 are less demanding regarding the performance of the wireless channel (latency, bandwidth), specific challenges need to be tackled with respect to coverage, heterogeneity, security and autonomy.

3. Technical requirements from manufacturing for 5G

To meet the needs of future manufacturing, the technology needs to adhere to industry-specific requirements with respect to timing, heterogeneity, security and safety, network infrastructure requirements, and network and service management. The 5G community can play a key role in delivering the unifying technology building blocks, supporting the manufacturers to realize significant efficiency increases through highly connected production chains.

Timing Requirements

The timing requirements vary depending on the industries and the specific setup of the plant. General classes for real-time communication have been defined. Typically, process automation industries (such as oil and gas, chemicals, food and beverage, power plants, etc.) require cycle times of about 100ms. In factory automation (e.g. automotive production, industrial machinery and equipment, consumer products) typical cycle times are 10ms. The highest demands are set by motion control applications (printing machines, textiles, paper mills, etc.) requiring cycle times of less than 1ms with a jitter of less than 1 μ s.

For motion control, current requirements are shown in Table 3.

cycle time	1 ms (250 μ s ... 31.25 μ s)
response time / update time	...100 μ s
jitter	<1 μ s ... 30 ns
switch latency time	...40 ns
cascaded switches	...100
redundancy switchover time	<15 μ s
time synchronization accuracy	...100 ns

Table 3 - Timing requirements for motion control systems

While the current wired systems are designed to meet these requirements, it remains challenging to achieve the same deterministic behaviour for wireless communication. For the mobile applications, as defined in use case family group 1, such a deterministic wireless data exchange will be key to be able to integrate robots and wearables into closed control loops.

In addition to the timing requirements that shall result in manageable Quality of Service (QoS) requirements, other specific application demands exist. They cover:

- exchange of devices at runtime (hot swapping, hot connect) without disturbing the network synchronization of communication schedules with application schedule.

Apart from stringent latency requirements, it is important in manufacturing that the transport of less time-critical data gets confirmed within pre-defined time intervals. This requires using confirmed communication services. The basic principles of such networks are defined in IEC 61158¹⁸ and IEC 61784¹⁹.

Heterogeneity Requirements

Besides the different timing and environmental aspects, one of the main challenges of state of the art systems is heterogeneity, which specifically addresses:

¹⁸ <http://www.iec.ch> - IEC 61158 - Digital data communications

¹⁹ <http://www.iec.ch> - IEC 61784 - Industrial communication networks - Profiles



- different media (copper, optical, radio) within a technology,
- different technologies (fieldbuses, industrial Ethernet, industrial Wireless, IT-networks),
- different protocols and services (real-time protocols and best-effort protocols on the same medium), co-existence issues,
- different vendors for networked components, interoperability issues,
- different implementation platforms (including standard IT systems and operating systems, legacy automation components, embedded devices, and IoT components),
- different handling and management concepts and tools.

The wireless systems in manufacturing will become increasingly diverse and experience continuous change with additional, mobile devices entering and leaving a single wireless collision domain. There is the need for wireless technologies that can adapt to these changing, heterogeneous environments, optimizing the usage of available spectrum for all available devices without violating fairness between the devices. On a technical level, this requires re-configurability of the radio (PHY and MAC) through software-defined networking interfaces and reconfigurable antennas, the ability to switch protocols in real-time, and the design of sensor protocols that leverage the capabilities of the wireless network.

On a higher level, there is the need for plug-and-produce protocols that can semantically describe their responsibilities, that require zero configuration by human workers, and that can adapt to a range of heterogeneous, manufacturing-specific protocol suites.

Managing the different aspects of heterogeneity at the different stages of the life cycle (i.e. from design and planning, assembling, commissioning, operation and maintenance, disassembling) is still performed using a widespread set of tools. 5G can take a key role to integrate and simplify the need for many tools, limiting also the need for additional tools.

Security and Safety Requirements

We need to avoid new vulnerabilities in mission-critical processes that may impact the overall guaranteed **uptime and throughput** of machines. Security becomes another key requirement in the connected factory. Typically, the resource-constrained, connected sensors and components are not capable of performing adequate encryption and decryption algorithms. Therefore, in automation, the zone concept is often used, i.e. defining zones with restricted physical and logical access and unencrypted communication inside them. Organizational efforts have to be done to ensure the consistency. It is however important, that the objectives regarding security are differently weighted compared to IT networks. Availability of the system is the most important objective, followed by integrity and confidentiality. Applying adequate security measures is difficult because of the heterogeneity of platforms, and management of security is a challenge because of the number of distributed components (up to several ten thousands of nodes inside a factory). With respect to safety, there is also the challenge to comply with safety integrity levels defined in standards such as IEC 61508 [xx] . Additional, the manufacturing industry has specific requirements with respect to proper and safe functioning of all machines and devices in a wide range of environmental condition. New technologies therefore need to comply with climatic conditions (dust, humidity, temperature, etc.), mechanical conditions (shock, vibration, etc.), and intrinsic safety conditions (e.g. limiting the power consumption to avoid explosions).



Network Infrastructure Requirements

5G is all about offering a unified infrastructure that integrates the different communication technologies manufacturers are confronted with. Infrastructure is needed to facilitate the distributed, indoor communication inside the factory, as well as to support longer-range, outdoor communication with connected goods, connected transport vehicles, remote diagnostics control rooms, customers, suppliers.

Considering indoor-communication in harsh manufacturing environments, there is the need to increase coverage to enable wireless communication even in harsh, metalized regions of a plant. Solutions need to be designed that minimize the need for gateways and other expensive infrastructural components, while optimizing coverage, availability and flexible reconfigurability of wireless nodes. Additionally, there is the need for intelligent technology that can monitor the wireless medium and prevent degradation of the network. For outdoor communication, the main requirements for the network relate to cost and re-use of already existing communication infrastructure, ubiquitous coverage and guaranteed performance.

Given the focus of manufacturing on uptime and increasing the production throughput, a network infrastructure is needed that complies with ultra-high service levels. The mission-critical nature of factory-related communication also demands a network infrastructure that is not solely managed by an external partner (e.g. telecom partner or IT partner). New solutions are needed that facilitate (co-) management of the network by the manufacturers themselves, giving them full control to alternative configurations in case the quality of the network may impact the production efficiency. Concepts such as network slicing, software-defined networking and network function virtualization are key building blocks within 5G, and may become cornerstones in tomorrow's communication infrastructure of manufacturers.

Furthermore, a smart transformation path needs to be developed to migrate over time the existing siloed industrial communication infrastructure to a future converged one. An evolutionary approach is likelier than "big-bang". Interworking needs to be developed across the following domains:

- Industrial fixed and wireless access technologies
- Common Industrial IT and Automation ICT infrastructure
- Macro cross- and intra company cloud with local private factory cloud, incl. resource management/control coordination across domains to guarantee required QoS

Service Management Requirements

The integration of distributed sensors, machines, parts, goods, vehicles, etc. increases the complexity to manage the data collected by all these computing resources. Rather than offering only high-performing connectivity, the network nowadays can also support the data and application management through networked services. Network components can be deployed that offer "Machine-Learning-as-a-Service", "Semantic-Interoperability-as-a-Service", "Protocol-translator-as-a-service". Such virtualized networked capabilities will help the manufacturers in managing and continuously optimizing the distributed intelligence of a production plant. Today, this intelligence is often spread between the manufacturing execution system, PLC controllers, SCADA controllers, local control systems, etc. This intelligence can typically not be addressed as it lacks interfaces to combine the intelligence into data-driven workflows. This hinders the rapid deployment of data-analytic



services that can drive e.g. faster change-overs, more optimized productions schedulers and less outages.

The large amount of new data sources require new concepts, which are flexible to decide, where the processing of the raw data is done. Sending large amounts of raw data to a remote data centres can end up being very costly and time consuming. Instead, solutions to do local/edge data pre-processing and filters helps to manage the overall data flow. Network-embedded big data technologies will be enablers to allow real-time data processing.



4. Capabilities not yet supported by existing technologies

The role of ICT and mobile wireless communications is key in the already existing factories and it will be clearly strengthened as part of future manufacturing strategies. In this section, we highlight the missing capabilities of current technologies to address the specific needs for Factory-of-the-Future, as described in section 3.

Missing capabilities of individual wireless technologies: 2G/3G/4G (LTE), SigFox, LoRa

We call low end IOT the services which require a very low bandwidth (<1 kbps), low energy consumption (10 years with no charge) and low cost (communication module between 1 and 5 \$). Today most of the low end IOT applications use the 2G (GSM) technology, due to the high maturity of the technology, which allows a high integration, and due its cost-effectiveness compared to the other generations.

Out of the cellular world other alternative solutions, such as Sigfox²⁰ or LoRa²¹, are available for the low end IOT applications. These solutions answer well the requirements of low cost and low energy consumption as well as large coverage (15-20 km of cell radius) and huge capacity (millions of objects per cell) that stems from the design of a dedicated air interface but also from the used spectrum band (868 Mhz unlicensed in Europe). Those technologies however do not handle mobility and especially hand over. In addition the bandwidth per object is very limited (100 bps, <1ko/day) and the latency is high (one full second may be needed to transmit a message), not allowing the deployment of real time applications. Due to the unlicensed band, these technologies lack dedicated quality-of-service guarantees. Indoor coverage is limited at 868 MHz which poses problems for use remote reading of smart meters for water, gas or energy, often located behind walls or down several floors, anyway far from the antennas. It is however possible to deploy LoRa technology at higher than 1 GHz bands to increase indoor coverage but then the cell radius decreases and so the cost increases. Broad deployment is hindered as the proposed standard specifications define only the physical layer, leaving lots of room for different implementations. Regarding security, the features that are related to SIM-card based authentication are not covered, and require the development of a new dedicated information system. Regarding localization capabilities, 3GPP technologies are including these for asset tracking. These capabilities are not available in LoRa.

The 4G technology (LTE) improves some of the limitations of the 2G technology, and in the next generations will support long range, low bandwidth, low cost and low energy connected things. The first target will be to introduce in the market a 5\$ LTE module (down from 25\$ as of today) with a 2 Mbps maximum data rate. This is higher than today's data rates of Sigfox or LoRa. On this regard the already defined LTE Cat 1 and the ongoing LTE Cat 0 specifications in 3GPP Release 13²² will ease some of the existing limitations with respect to increasing coverage, e.g. to reach out to water meters buried in basements.

5G will go further with more power saving techniques (in order to reach 15 years without charging batteries) and more flexibility in terms of target performances (reliability of up to 99.999% and ultra-

²⁰ <http://www.sigfox.com>

²¹ <https://www.lora-alliance.org/>

²² <http://www.3gpp.org>

low latency). These specific characteristics will make 5G in particular interesting for the long-range communication scenarios discussed in section 2.

Missing capabilities to manage heterogeneity and co-existence of wireless technologies

To cope with the increasing diversity of wireless IoT systems in manufacturing, there is the need for novel capabilities to ensure the same level of reliability as offered in wired architectures. Given the non-deterministic behaviour of the wireless medium, new challenges arise to manage spectrum in particular in environments where the number of wireless applications and devices are increasing. Compared to other industries, the wireless industrial internet has one of the most stringent requirements in terms of latencies and reliability, in particular for use case family 1 grouping time-critical closed loop communication scenarios. Open questions still exist to manage:

- Co-existence of different wireless protocols and systems,
- Co-existence of different wire protocols
- Interoperability between communication systems
- Seamless engineering taking into account collected real-life data

To manage the co-existence of wireless technologies, new protocols are needed to manage the co-operation of technologies working in the same frequency band, or to spread the usage over multiple frequency bands in a coordinated and adaptive way.

The main objective is to increase the capacity of current wireless technologies through self-organizing 5G technology, and prepare for future scenarios where up to 100 sensors can be operated per cubic meter without compromising the availability of robots are connected machines.

Missing capabilities for plug-and-produce integration of sensors, machinery and people

The integration and re-configuration of new machines, PLCs, robots, sensors and software tools, still requires a lot of custom programming. As a result, the flexibility of current production systems is typically limited to the production of a set of pre-defined product types.

To take full advantage of flexible production systems, the effort to add new machines or sensors should be minimal. Referring to the plug-and-play concept in computing, the plug-and-produce concept has been introduced in manufacturing. To realize the plug-and-produce concept, proper data formats and protocols are still missing. In particular for communicating change-over related data, machine configuration capabilities and settings to manufacturing execution systems, there is a need for common standards.

5G technologies can play a key role in the convergence between on the one hand promising internet technologies (e.g., COAP, MQTT, EXI, ETSI LWM2M, etc.) and on the other hand industrial protocols (e.g., AutomateML, OPC UA, ODVA Common Industrial Protocol, FINS communication, MTConnected, etc.). The internet technologies are valuable in view of the migration of existing systems towards more service-oriented architectures. These technologies are not industry specific and therefore may get widely adopted in low-cost communication modules. The adoption of generic IoT protocols in industrial protocol stacks may bring added value and competitive advantage, and could become a cornerstone to facilitate seamless plug-and-produce integration in manufacturing. Migration concepts for an evolution from pure legacy systems to standardized open systems, that adopt open internet technologies, need to be supported.



Missing capabilities for cost-effective network and service management by factory operator

Current networking technologies don't offer the capabilities to easily manage and optimize the network performance for a diverse set of wireless technologies, protocols and data formats. In manufacturing, commonly used technologies are 2G/3G, WirelessHart, ISA100.11a, Wifi and ZigBee. As the majority of machine interactions are still executed using wired technologies, there is still a lack of technology to monitor and optimize wireless networking.

Once devices are discovered and configured properly, taking advantage of plug-and-produce configuration concepts, there is a need for network and service management functionalities to:

- manage workflows and data interaction patterns between an increasing number of sensors, machines, robots, wearables, etc.;
- allocate the proper computing resources in the cloud, on the edge or at sensor levels to ensure compliance with application-level service agreements;
- leverage machine-learning and data analytics capabilities distributed in the network, to a multitude of vendor-specific platforms, contributing to a unified, intelligent data intelligence platform;
- manage and optimize the wireless network topology and performance, according to real-time changing networking conditions

Adoption of internet technology will enable easier integration of workflows through standardized interfaces. Each of the workflows may have different requirements with respect to bandwidth, latency and availability, and as a result the cost for networking should be linked to the needs. Also, end-to-end communication may require the integration of public cellular networking technologies (such as 5G) with private networks such as pico-cells or meshed networking topologies. The concepts of network virtualization, software defined networking and distributed cloud resource management can be leveraged to give the factory operator a unified view on the network. There is the opportunity for the 5G community to extend the management capabilities beyond the networking aspects, and include networked services for security, data analytics and cloud/edge computing. Suitable solutions for cloud-based security are still missing, in particular to support scalable generation, distribution and revoking of security certificates.

To support the future use case families, there is a need for management capabilities across (wireless) networking technologies, to provide visibility over the intra-factory and wide-area network performance and to offer the networked services as building blocks for efficient manufacturing systems. With such infrastructure in place, the design process can also be further streamlined incorporating real-life data from production and product usage to deliver novel, data-driven computer-aided designs.



5. Business and policy aspects

The trends of servitization and global value chains (see section 1) are changing the manufacturing sector profoundly. Oxford Economics²³ predicts that 53% of manufacturers will offer smart products by 2016, and there are market reports²⁴ that indicate that manufacturers will get by 2025 more revenue from services than from products. The huge amount of data collected before, during and after the production of finished goods have enormous potential for usage to support decisions, facilitate collaborative manufacturing or to drive next-generation innovations.

New business models leveraging data collection within the manufacturing context

The connection with suppliers, with the supply chain, with engineering and manufacturing services and with other manufacturers promote the growth of new data-driven business models either by service providers or by manufacturers.

While the manufacturer can have an important role on the product improvement and product-oriented models, other service providers can be more efficient in the data oriented business models due to their expertise in ICT solutions rather than in manufacturing products.

Examples of new roles or services are:

- *Unified-network manager*: this refers to the party managing the communication network infrastructure. In a manufacturing context, this may involve many different wireless network infrastructures, deployed either in private or public areas. Questions that need to be answered are: Who is the owner of the infrastructure? How will co-ownership of network and manufacturing infrastructure be managed? Who will be liable, in case of failure along the communication/production chain?
- *Remote factory manager*: the availability of highly reliable networks may become a key driver for new business models and new actors that take the responsibility for remote SW upgrades, remote operations monitoring, remote maintenance, etc.
- *Machines-as-a-service/ equipment-as-a-service*: this implies the outsourcing of operations and maintenance of particular machines or equipment. Thus manufacturers are not buying the production machine, but rather rent or lease these machines, and have the machine vendor take care about operations and maintenance. Rolls-Royce has set the scene with their airplane engines, selling hours of operation instead of engines.
- *Provider of smart clothing*: the integration of electronics in textile and wearable devices, opens new business opportunities that could be taken by existing or new actors in the value chain. Given that an industrial environment is usually not so friendly for devices (noise, vibration, temperature (hot or cold), dirtiness, chemical elements, etc.), providers of smart clothing may also deploy very specific research activities.
- *Provider of flexible robotic services*: the increased autonomy of robots may fuel the introduction of new services that apply robotics to execute dangerous, dull and dirty tasks

²³ <http://www.ptc.com/topics/manufacturing-transformation/oxford-research/>

²⁴ <http://news.verizonenterprise.com/2015/07/servitization-iot-manufacturers-usage-data/>



In many of these new business activities, not only sensing and communicating but also data analysis becomes a key aspect. Also with respect to data analysis, it can be expected that new actors will come into the game of optimizing the connected factories.

New business models leveraging data collection outside the manufacturing context

In general, the manufacturer loses connection with the product as soon as the product leaves the factory. The only link between manufacturers and products is established by the maintenance services offered or the spares department of the manufacturer.

The knowledge of the behaviour of the product along the whole lifecycle has the potential to lead to significant improvement of the product design, and to introduce new data-driven business services. The need to improve the product design will drive the need to collect more product-related data.

The services focused on product performance are a new business topic as well. In this case, the product is at the customer, and the improvement of performance is the key aspect. So, product productivity and performance data are a key aspect, but in this case, the goal is to improve the product behaviour on site reducing its maintenance, consumption, stops, and more.



6. Suggested research & innovation topics in addition to current 5G vision

A 4th industrial revolution is about to take off. This revolution is triggered by the price drop in electronics, and the resulting low-cost integration of these electronics into mechanical components. The scale of information that will be exchanged across machines, robots, engineering & production intelligence and the workforce (blue and white collar workers) will grow several orders of magnitude. Moreover, apart from traditional IoT sensors, industrial sensors (3D scanners, computer tomographs, light-wire interferometers, LIDAR sensors) will produce and will need to operate on not only big but thick data (3D mesh models, 3D point clouds, 3D color maps). For manufacturing, there is the potential to revolutionize the shop floor and to introduce new concepts of highly efficient and highly flexible workshops.

According to the current 5G roadmap, it is the ambition to deliver the next-generation communication networks and services, providing an order of magnitude improvement in performance in the area of more capacity, lower latencies, more mobility, more location accuracy and increased reliability and availability. To be capable to support the expected revolution in manufacturing, the 5G roadmap needs to take into account stringent industry-specific requirements. In this regard, the following seven recommendations cover focus areas for upcoming 5G research and innovation activities to make sure 5G can also meet the expectations in the manufacturing industry.

Recommendation 1: Focus on high throughput zero defect manufacturing with research on ultra-reliable broadband wireless deterministic communication

Increasing the throughput of production systems and reaching zero defect manufacturing processes, is a key concern for all manufacturing companies. Opportunities arise with the introduction of wireless wearables, 3D scanning technologies and the integration of collaborative & mobile robots or unmanned logistic drones. These use cases, however, are amongst the most challenging with respect to latency and availability. This holds in particular for use case family 1, grouping the time-critical use cases that participate in the real-time closed loop control systems. The latter have latency requirements up to 1ms, with jitter limited to 1 us, and require ultra-high availability.

To realize ultimate uptime and throughput, we recommend to focus the 5G research on deterministic wireless communication with investigation of suitable radio waves, new wireless MAC protocols and software-defined networking concepts that are capable to realize such low latencies, with high energy efficiency per bit and long range. We recommend to target latencies up to 1ms in settings with up to 100 wireless sensors in one cubic meter. This corresponds with future scenarios where sensors inside robot and machine sensors are no longer wired but use wireless technologies.

Recommendation 2: Focus on high availability and uptime with research on proper security mechanisms and ubiquitous coverage

While increasing the throughput has a direct relation with the profitability of a production system, the integration of embedded computers and electronics, connected with the internet, introduces new security vulnerabilities as hackers may compromise the high availability through cyber-attacks. Adequate security mechanisms are needed that take into account the limited capabilities of constrained sensors, as well as the additional vulnerabilities if part of the security functions are offloaded to the cloud. Additionally, the availability may be impacted by malfunctioning robots, sensors or machines that are out-of-range of wireless gateways, or other meshed wireless nodes. The



factory, with a lot of metal in the environment, could be used as worst-case scenario to evaluate the coverage, coexistence and interference management of 5G wireless technologies (including satellite and High Altitude Platforms), both indoor and outdoor.

Recommendation 3: Focus on lowering the TCO of factory automation solutions with research on network capabilities to manage heterogeneity

The total cost of ownership of factory automation systems will be largely determined by its capability to manage heterogeneity of device types, wireless technologies and vendors in a cost effective way. Regarding wireless technologies, there won't be a single technology that can meet the different, varying requirements of the 5 use case families. Technologies such as 2G/3G, LoRa, SigFox, Wifi, Bluetooth Low Energy, ZigBee, WirelessHart and ISA100.11a will co-exist and proper management of spectrum will be needed. The latter two technologies are examples of industry-specific technologies. We recommend research that evaluates cost-effective ways to extend the management to such vertical-specific protocols with specific support for device to device mobile opportunistic offloading mechanisms and to develop further specific interference management and network performance degradation strategies, which ensure deterministic wireless performance as the number of wireless devices & sensors per m3 grow . Additionally, there needs to be support to manage custom network topologies that may combine both shared, public infrastructure with private on-site networking infrastructure.

Recommendation 4: Focus on high flexibility with research on plug-and-produce capabilities by adopting internet technologies

To realize highly flexible production lines, it is key that each of the components has semantic descriptions, and that common data formats and protocols are designed to facilitate immediate change-overs once a new product type is scheduled for production. We recommend research on integrating and interoperating the typical internet technologies for constrained devices (IP, COAP, MQTT, etc.) in manufacturing-specific data formats and protocol stacks (AutomationML, OPC UA, OODA, etc.). This will allow the integration of low-cost, high volume communication modules to leverage the plug-and-play concepts of internet technologies, while the industrial protocols are needed to understand the parameterization and adaptation of settings in machines, MES or other production-related components. We believe that SMEs can play a differentiating role in designing highly efficient and highly flexible high-tech (small scale) workshops, bringing manufacturing value back to Europe.

Recommendation 5: Focus on new data-driven business models with research on networked data management capabilities

To fully grasp the benefits from collecting data from thousands or millions of sensing nodes, there is the need for an intelligent network that offers capabilities to filter and analyze data, particularly for specific sensing technologies that produce big data at high speed; e.g. 3D scanning technologies. Research is recommended that evaluates how concepts like SDN, NFV and SFC can be used to distribute for example Machine Learning, 3D computational geometry capabilities between constrained nodes, edge nodes and the cloud.

From a business perspective, we recommend studying the different business models that could come into play by offer of data-driven services based on gradual introduction of product-service systems²⁵ by the manufacturing industry. New business models could be built around „Machine-as-a-Service“-concepts, „Manufacturing-Capacity-as-a-Service“-concepts, „Predictive Maintenance“-services, „Virtual product design“-services that integrate real-life usage data from connected products, „Virtual Network“-services, etc. New actors need to be identified, and aspects like data ownership need additional research. Research is also required to align the business models of manufacturing industry with long infrastructure return of investment (ROI) cycles and network operator business models and faster communication network generation innovation cycles.

Recommendation 6: Revisit the legislative framework, standards and social acceptance

The evolutions in digital manufacturing will also require the proper adaptations to legislation, standards and social acceptance. A recent workshop on digitalization and innovation in digital manufacturing²⁶, with DG-Connect and EFFRA as co-organizers, concluded there is the need for a proper legislative framework, e.g. for the co-working of robots and humans. Additionally, there is the need to address liability issues and privacy concerns. To ensure social acceptance of the new technologies, promotion activities should be also considered.

To conclude this section of recommendations, we like to stress the importance of adoption of new technologies by SMEs, as the manufacturing industry is mainly driven by the innovative power of this group of companies.

Recommendation 7: Build a specific strategy for 5G & Manufacturing SMEs

To conclude this section of recommendations, we like to stress the importance of adoption of new technologies by SMEs, as the manufacturing industry is mainly driven by the innovative power of this group of companies. It is now established as a good practice in the manufacturing domain the I4MS (ICT Innovation for manufacturing SMEs) model for innovative technology adoption in manufacturing SMEs. The I4MS (www.i4ms.eu) model combines the establishment of a network of competence centres in key ICT technologies for manufacturing (HPC Simulation, CPS/IoT, Robotics, Laser) and the realization of innovation experiments in manufacturing SMEs; i.e. first of a kind deployment of advanced manufacturing services/applications. So far, over 275 experiments are planned or in progress as part of the I4MS Programme, supported by over 65 European Competence Centres in their fields of expertise. It is recommended that the I4MS best practices and lessons learned are used in the adoption and introduction of 5G-based services and applications towards manufacturing SMEs and suitable liaison is established towards I4MS community.

²⁵ PSYMBIOSYS – Product Service Symbiotic Systems www.psymbiosys.eu

²⁶ The report is available on the EC website at the following URL: <https://ec.europa.eu/digital-agenda/en/news/european-co-operation-innovation-digital-manufacturing>



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