Technology Roadmap

SMART advanced manufacturing

Sep 8, 2019

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1 Introduction

Manufacturing forms the backbone of the economy of many countries in the European Union. Manufacturing is a vital area, whose role is increasingly seen as fundamental towards European recovery and sustainable growth. It is a relevant Key Enabling Technology for the current shift towards a 'Competitive Sustainable Globalisation', addressing grand socio-economic and environmental challenges of our times.

Advanced Manufacturing Technologies are perceived as key players in the new industrial revolution. For example, 3D additive manufacturing permits the production of much smaller batches, making low cost customised production possible and opens new market niches for innovative SMEs. Tomorrow's companies are expected to use highly efficient processes in terms of energy and raw materials use; they will incorporate recycled and bio-based materials, design products aimed at reuse and disassembly, and promote the adoption of sustainable business models based on circular economy, industrial symbiosis and value chain integration.

Furthermore, the new possibilities brought by advances in information technologies and their application in industry, mean that information technologies and knowledge become closely interwoven with industrial equipment and processes, converging towards virtual manufacturing, - or immersive reality. Concepts such as internet of things, cyberphysical systems or cloud computing, are now commonly used in the design and development of new products and services. This will bring important challenges to people involved in manufacturing, who will require an adequate working environment, new tools and lifelong training specifically devised for advanced manufacturing factories.

This technology roadmap illustrates the technology areas and developments that are needed to take a big step forward in the competitiveness of the manufacturing industry in Europe.

This updated Technology Roadmap is the result of a reflection process carried out within the framework of SMART: Advanced Manufacturing Eureka Cluster, led by important players from European industry and completed with the contribution from academy and research organisations. The roadmap provides the vision of strategic challenges identified in **several** high impact **industrial sectors**: **Aeronautics, Automotive, Consumer Goods including Pharma and Medical Devices, Capital Goods and Railways,** in which the technologies and new solutions developed within the cluster projects shall be mainly applied.

Our aim is for this to be a living document that grows and improves along the way with viewpoints of relevant agents and entities from the considered industrial sectors.

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2 Technology Roadmap structure

SMART Technology Roadmap is developed based on two building blocks:

1. The **industrial challenges** that manufacturing companies face, with the gaps, barriers and bottlenecks that they need to overcome in order to improve their competitiveness (Chapter 3)
2. The **enabling technologies** and trends that are pushing forward the development capabilities, and create the basis for development of innovative solutions (Chapter 4)

Finally, based on the two previous blocks, 6 **research and innovation domains** are defined to address the industrial challenges. (Chapter 5).

Industrial challenges

- Aeronautic
- Automotive
- Capital Goods
- Consumer goods
- Railway
- Others

Enabling technologies

- Material processing technologies
- Mechatronic technologies and systems
- Flexible, adaptive and collaborative robotics
- Information and communications technologies
- Production technologies

→

Research and Innovation Domains

- Advanced Manufacturing Processes
- Intelligent and adaptive manufacturing systems
- Digital, virtual and efficient companies
- Person-Machine collaboration
- Sustainable manufacturing
- Customer based manufacturing

3 Industrial challenges to be solved

3.1.1 Grand Challenges

The great challenges to be addressed by the advanced manufacturing industries are mostly related to the challenges their main customers are facing, which are directly related to cost savings, delivery times, product quality sustainability, digitalisation, and added value solutions for a global market. Below is a collection of challenges identified by the identified industrial sectors, see Appendix 1 for more details.

Increased market and cost pressure

- Reduced cost
- Reduced time to market
- Supply chain integration and connectivity
- Integrated design and manufacturing development processes
- Flexible, adaptive manufacturing and assembly
- High rate production of customised products
- Integration of modular systems
- Demands for new business models related to advanced manufacturing.

Rising product complexity

- Added value products, solutions and services
- Higher requirements of zero-defect manufacturing and increased precision in any size of product
- Implementation of user-guided creativity and innovations
- Integration of new materials and nano-intelligence
- Advanced metrology systems embedded in manufacturing processes
- Complex products to be manufactured at a highly restricted budget
- Efficient use of resources
- Need for new manufacturing processes and integration of existing manufacturing processes, including additive manufacturing.

Challenges with digital transformation

- Incorporation of intelligence into the product design by means of information management
- Assured connectivity of machines in highly complex cyber-physical manufacturing systems, plants and ecosystems
- On-line monitoring and control and auto tuning of manufacturing systems
- Interoperability of equipment
- Increased demands of simulations, ICT and electronics to add intelligence in the process
- Efficient use of artificial vision and augmented reality for manufacturing, assembly and maintenance
- Need of improved data handling and use of artificial Intelligence
- Cybersecurity issues.

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Climate challenges, low CO_2 emissions

- Increasingly restrictive fuel emission regulations
- Higher demands for lightweight products
- Achieving intelligent, safe, fast and sustainable transport with new and more efficient propulsion methods and fuels
- Sustainable production and green manufacturing systems and value chains
- Increasing the resource efficiency and striving for zero waste production.

4 Enabling Technologies

The achievement of the transformations planned for the European Manufacturing Sector requires a coordinated research and innovation effort, integrating technological developments from different areas, with a collaborative and complementary vision.

The Enabling Technologies that can be considered key for the Research and Innovation activities to be prioritized in this Programme are included in the following areas:

- Material Processing Technologies
- Mechatronic Technologies and Systems
- Flexible, Adaptive and Collaborative Robotics
- Information and Communication Technologies
- Production Technologies

4.1 Material Processing Technologies

The current and future requirements for manufacturing processes are related to efficiency, sustainability, and reliability criteria. The efficient use of resources (raw materials involved in the manufacturing processes and energy), the minimization of waste (material and energy) and the assurance of the quality and safety of the processes are leading the evolution of the so called conventional processes and the irruption of new processes such as additive or nano-micro technologies.

Additionally, new advanced materials with special functionalities are emerging and require a special effort from the process point of view to move them from the laboratory scale to the industrial productive level.

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Technologies in this area include:

1. Manufacturing processes able to handle new, difficult to process materials such as:
    a. new metallic alloys
    b. new composites and thermoplastic materials
    c. nano materials
    d. ceramics
    e. flexible Sheet-to-Sheet (S2S) and Roll-to-Roll (R2R) metals
    f. in-built plastics electronics, and new materials and greater use of space on CMOS
2. Advanced joining of hybrid materials
3. Additive manufacturing and combined additive/substractive or substractive/additive processes
4. Generation of new part functionalities through surface removal and manufacturing processes
5. Large volume patterning at nano-scale, such as photolithography
6. Nanotechnology and microengineering
7. Laser processing
    a. of composites and dissimilar materials
    b. mass production of individual items
    c. product customization
    d. colour marking
    e. fabrication and laser treatment of functional surfaces and advanced materials.

4.2 Mechatronic Technologies and Systems

The mechatronic concept comprises the technologies and solutions concerning machine mechanical elements (structural elements, components), peripheral components such as clamping and handling elements, and the control and computing capabilities required to perform the tasks that those components are required for.

Those performance capabilities will fulfil industrial requirements related to performance and energy efficiency, adaptability to changing production scenarios, reliability of machine performance and part quality and effective collaboration with other machines, systems and humans.

Precision technologies and metrology concepts will be applied not only to specific high precision systems, but also to conventional machines to ensure the fulfillment of productivity and reliability increasing requirements. The use of complementary technologies (optics, photonics) will gain strategic importance in this field.

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Under the paradigm "Industry 4.0" the challenges connected to mechatronic technologies are oriented towards generating machines and systems that are smart, self-learning based on the knowledge acquired from different sources, adaptive, and inter-connected.

Examples of these technologies are:

1. Advanced on-line process monitoring and control systems for process-, machine component-, machine - and shop floor level.
2. Control technologies. Supported by the theoretical models or artificial intelligence methods and the real data provided by dedicated monitoring systems, advanced control systems will allow optimisation of the mechanic systems to be driven and its energy usage, and the adaptation of the system's behaviour to the process and production requirements.
3. Machine diagnostics using convolutional neural networks.
4. Advanced non-contact, and machine vision-based on-line measurement tools for process and machine performance monitoring in manufacturing processes
5. Advanced automated non-destructive techniques (NDT) for part inspection for zero defects manufacturing and onsite maintenance purposes.
6. Cyber Physical Systems (CPS). The connectivity of the (advanced, monitored and controlled) mechatronic systems will enable the development of safe, energy-efficient, accurate and flexible or reconfigurable production systems. This includes the introduction of smart actuators and the use of advanced end-effectors composed of passive and active materials for complex part manipulation or assembly. CPSs enable higher levels of modularity and increased performance and scalability in dynamic situations.
7. Multidisciplinary technologies integration for the complete life-cycle optimisation of production systems.

4.3 Flexible, Adaptive and Collaborative Robotics

The use of robotics in production is a key factor in making manufacturing within Europe economically viable. In order to improve competitiveness, manufacturing unit costs need to be reduced and robotics provides a means to achieve this. Locating manufacturing in Europe reduces delivery times and costs and robot assembly techniques allow a much greater degree of customisation and product variability. The market for manufacturing robots is strongly expected to grow through diversification into industries with lower volumes, and into areas of manufacturing where manual assembly has previously moved away from Europe.

Robots are also the key drivers of flexibility, adaptability and reconfigurability. New automation concepts such as Human Robot Collaboration (HRC) and Cyber-Physical Systems (CPS) are recognized as having the potential to impact and revolutionize the production landscape. Increasing the flexibility of industrial robots and providing automation systems that provide faster more intuitive configuration are important goals for future production systems.

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Machines and productive systems need to interact with humans in different stages of the production chain, such as training, set-up, service, production, while sharing information and knowledge in a two directional flow.

Robots increase the repetitiveness, reliability and performance of processes (e.g. during inspection and assembly). Automation is also important for supporting the operator in the workplace, by decreasing stressful, hazardous or repetitive manual tasks.

Key technologies include:

1. Integration of cognitive functions into machines and robots for adaptability to changing manufacturing requirements
2. Improved visualisation and analysis of complex production flows
3. Advanced operator information systems, production and process model-based systems to support operator decisions
4. Complex control systems involving the human in the control loop (HITL), supported by appropriate sensor systems and modeling and simulation tools
5. ICT solutions for the interaction between humans and machines.

4.4 Information and Communication Technologies

Digitisation is transforming manufacturing and driving new business models. Integration of ICT, data analytics, Artificial Intelligence and ubiquitous connectivity is becoming one of the fundamental challenges for manufacturing research agents and industrial companies in the complexity of the current industrial and social scenarios.

On the one hand, the globalization of society and companies and the derived mobility and communication requirements and opportunities configure a picture where IC Technologies play a fundamental role.

On the other hand, the production paradigm is also moving, from a production centered model to a human centered model and from human force driven to knowledge driven manufacturing.

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Technologies related to these new requirements must be integrated, leading to connected, interactive, collaborative, intelligent and adaptive machines, processes and production systems:

1. Simulation techniques in manufacturing and assembly processes to achieve first-time-right and increased production rates
2. Use of big data and evolutionary algorithms for processes diagnosis, monitoring & control as well as predictive maintenance
3. Comprehensive modelling and simulation tools that support cost models linked to design, productivity, end of life and recycling
4. Advanced modelling and simulation tools for manufacturing process design and optimisation, including machine-process interaction and ergonomics
5. Streamlined simulation tool calibration and correlation methods through experimental data.
6. Integrated knowledge-based systems supporting the product and process archetypes approach, with self-learning capabilities for semi-automatic design rules update.
7. Use of a multivariable and multi-objective optimisation engine in conjunction with simplified meta-models of manufacturing processes and systems (i.e. manufacturing cells, cyber physical systems composed by several machines, entire production lines, etc.) in order to quickly identify optimal solutions to manufacturing problems.

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4.5 Production Technologies

Technologies for production strategic planning, design and optimisation will also play a fundamental role, providing tools for a strategic view of the manufacturing challenges. These technologies cover from the use of advanced simulation, verification, programming tools to technologies dealing with strategic decision making. The concept of smart factory and digital factory is one of the challenges in this area. For this purpose, advances in ICT in terms of computing power, communication speed or multi-modal visualisation are enabling further development of simulation and forecasting tools.

Examples include:

1. Virtual factory models that enable exploring better different design options, evaluate their performance and virtually commission the automation systems, before the real production line or system is deployed and can be used after the production line installation as digital twin for monitoring, controlling and planning purposes
2. ICT solutions for data acquisition, storage and processing. In an industry 4.0 context, data analytics and business intelligence tools, allowing the comprehensive evaluation of data coming from many different sources play a crucial role for supporting business decision making.
3. ICT solutions for secure, high performance and open communication and platforms. The cloud will be the meeting place for provisioning functionalities and services that are reliable, secure, and guarantee performance. Open standards will ensure the full inter-operability in terms of data and applications, and Cyber security technologies will play a critical role to ensure the security of these massive data transitions.
4. Simulation, concurrent engineering methods and prototyping technologies for shortening development and certification cycles.
5. On-demand production systems for customized parts, production systems that enable to iterate part designs quickly and enable to bridge the lifecycle from rapid prototyping to industrial production.
6. Servitization Technologies. From Product centered approach to Services/Solution centered approach. Towards manufacturing as a service and additional services for manufacturing operation support.
7. Virtualization and digitization of the interrelation between manufacturing and new business models. New business models need to have tools to support the company to design and test them before they are implemented through products, services and manufacturing processes.

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5 Research and innovation domains

The challenges that the European manufacturing industry? faces, as explained in previous chapters, require a coordinated and broad research and development action. The SMART technology roadmap relates to complementary initiatives and agendas at European level focused on advanced manufacturing, such as Manufuture, EFFRA and EIT Manufacturing.

SMART cluster roadmap identifies that the transformation towards more advanced and efficient factories will require a pursuit of a set of research and development priorities along six Research and innovation domains:

1. **Advanced Manufacturing Processes**, including innovative processing for either new and current material or products.
2. **Intelligent and Adaptive Manufacturing Systems**, including Innovative Manufacturing equipment at component and system levels, mechatronics, control and monitoring systems
3. **Digital, Virtual and Efficient Companies**, including Factory design, data collection and management, operation and planning, from real time to long term optimisation approaches
4. **Person-Machine Collaboration, including** the enhancement of the role of people in manufacturing
5. **Sustainable Manufacturing towards a circular economy,** including innovative processes and systems for sustainability in terms of energy and resource consumption and impact on the environment and circular economy business models for the manufacturing industry.
6. **Customer-based Manufacturing**, including involving customers in manufacturing value chain, from product process design to manufacturing associated innovative services, and agile and ultra-fast digitized manufacturing concepts enabling new business models such as manufacturing as a service or on-demand production of custom parts.

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5.1 Advanced Manufacturing Processes

Advanced manufacturing includes all types of innovative processing for either new and current material or products. It contains the following research topics:

- Processes addressing challenges related to new emerging materials
- Development of low-cost composite materials and processes for high volume production
- Integration of new advanced materials for the design and construction of mechatronic elements and systems. The application of new materials (lighter, active, intelligent) gives an opportunity to overcome the current machines' performance limits
- Effective integration of different manufacturing processes: additive manufacturing, machining, laser, chemical, ultrasonic vibration, laser, cryogenic or other supported machining processes
- Resource (material, water and energy) efficient materials removal processes for advanced metallic alloys and other materials
- Generation of new part functionalities through surface manufacturing processes
- Additive manufacturing and combinations thereof, research, not only in the fundamentals of the process, but also in the combined optimised strategies and manufacturing guidelines
- Advanced joining and manufacturing for disassembly and recycling/reuse of advanced material combinations
- New processes and equipment for high efficiency production, with zero defects and high precision
- Nanotechnology and microengineering
- Extending laser processing capabilities beyond their current position, allowing new and challenging applications and basic research on materials processing.
- Research on innovative physical, chemical and physicochemical processes.

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5.2 Intelligent and Adaptive Manufacturing Systems

The research area encompasses innovative manufacturing equipment at component and system levels, mechatronics, control and monitoring systems. It contains the following topics:

- Development of real time measurement systems, sensors and algorithms for process diagnosis and control. This includes any type of sensor and development of complex multisensory networks including multi-sensor fusion strategies for process monitoring, integrated with cognitive systems for intelligent and self-optimising production equipment.
- Research on data monitoring for the whole manufacturing life cycle:
    - Real time process optimisation
    - Production strategies optimisation
    - Energy consumption optimisation
    - Machine components' life prediction, life increase and replacement and reuse strategies definition
    - Optimisation of machines and systems designed by the feed-back information integrated into theoretical design models
    - Process adaptation to flexible rates
- Development of sensors and systems for process diagnostics, multi-sensor fusion and process monitoring and visualisation, integrated with cognitive systems and simulation tools for intelligent and self-optimising production equipment. For this, multi-objective, multi-variable models are required. Furthermore, "hybrid" models combining the "physical" simulation with the real data obtained from the human experience and the data provided by dedicated monitoring systems are also needed
- Research on integrated knowledge-based systems supporting the product and process archetypes approach, with self-learning capabilities for semi-automatic design rules update.

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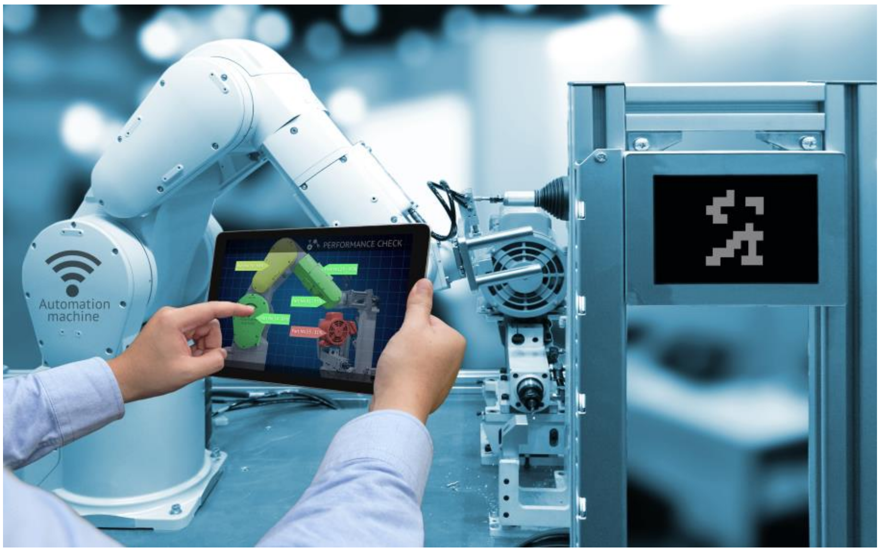
5.3 Digital, Virtual and Efficient Companies



The area involves factory design, data collection and management, operation and planning, from real time to long term optimisation approaches. It contains the following topics:

- Development and implementation of more effective design for manufacturing techniques based on virtual models and simulation tools allowing gathering feedback from process monitoring and quality inspection systems and translating it in concrete suggestions for improving the product design in view of its manufacturing, with consequent cost reduction and quality improvement (i.e. rework minimization).
- ICT solutions for factory floor and physical world inclusion. Methods and tools are required to properly design and manage production systems that are becoming more and more complex and need to be adaptable to changing market requirements (customisation, flexible rate…).
- Systems for complete traceability of tools, production progress and products in real time
- Cybersecurity and secured concepts for communications and cloud computing
- Virtual reality and augmented reality simulators for planning and operation of manufacturing system
- AI and ML solutions to address challenges such as intelligent planning and scheduling, flexible production line design (lot-size-one), more autonomous machine operation (for example to inspect and repair itself without any human intervention)
- ICT solutions for:
    - Data acquisition, storage and processing. In an industry 4.0 context, data analytics and business intelligence tools, allowing the comprehensive evaluation of data coming from many different sources will play a crucial role for supporting business decision making.
    - Real machine and process data during production
    - Supply chain needs and situation
    - Machine global park data
    - Industrial and economical macro data for business decision making.

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5.4 Person-Machine Collaboration

Focus on enhancing the role of people in manufacturing by improving their interaction with software and machines: developing inclusive workplaces, with high interaction capacity, easy to operate and with high personal safety. The research domain includes the following topics:

- Developing functions with cognitive abilities that contribute to a reduction of programming and configuration requirements. There are clear benefits in reducing the time and skill needed to reconfigure and adapt systems to new processes. This includes ICT solutions for the interaction between machine and human.
- Concepts for smart use of virtual or augmented reality improving operations/process flow visualization systems.
- Friendly and inclusive work environments (noises, emissions, vibrations, loads, repetitive tasks, ergonomics).
- Raising workers' capabilities by means of smart human machine interphase solutions and real time information and analysis.
- Concepts for safe automation of operations and of system integration
- Tools to ease this interaction, such as virtual reality or augmented reality, semantic interfaces adapted to the skills of the momentary operator, and tools to include the knowledge provided by the experience and skills of the operators to the machines will be required. Safety and improved ergonomics will also be critically improved by using these techniques.
- New machine architectures, including collaborative integration of robots for flexibility and multi-processing capabilities.
- Solutions where artificial intelligence is supporting a human to make better decisions in highly controlled environments with low risk tolerance. Improving the understandability of AI decisions is crucial to improve the trust of the human operators on the AI systems.
- Intuitive programming devices, aimed at multimodal tasks and based on new dialogues between humans, machines and robots.

- Ergonomic human-robot collaboration, for human performance improvement and error minimisation. Coexistence of robots integrated with manual processes.
- Capability to reconfigure industrial robots and their applications with regards to software and hardware. Improvement of usability by the adoption of Intuitive programming
- Intuitive, effective and safe Interaction with human, other robots and other systems within a production environment.
- One of the fields of improvement required by robots to extend their application beyond handling operations is their kinematics and dynamics, in terms of accuracy, repeatability, dynamic stability, controllability.
- Perception ability adapted to the field of automation, suitable choice of sensing modality, efficient signal and data analysis, as well as generating the maximum information output from the data at hand. Guaranteed safe perception is also a key issue.

5.5 Sustainable Manufacturing Towards a Circular Economy

Implementing circular economy is central to the competitiveness and sustainability of European manufacturing. Circular economy refers to the decoupling of growth from resource consumption through the optimisation of resource flows and recirculation of products, components and materials in value-chains and production systems.

From digitisation and automation to IoT and additive manufacturing - advanced manufacturing technologies are key enablers of circular business models which deliver waste reductions, increase resource security, supply chain resilience and manufacturing competitiveness. Implementing circularity is a central pillar of sustainable manufacturing alongside industrial energy efficiency, which together can deliver low carbon and clean growth.
Circular economy strategies include, but are not limited to:

- product-service systems
- eco-design and life cycle optimisation
- re-use, repair and remanufacturing
- resource recovery and recycling in an industrial symbiosis.

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Further research is required to understand how advanced manufacturing technologies can enable the implementation of circularity and ultimately scale up the recirculation of resources in high impact industrial sectors.

Key Research Themes

- Digital Material Passports
  - Optimising the recirculation of materials in production systems requires information regarding material composition, optimal productivity, and how-to disassembly and recycle the component or product in question
  - Embedding digital material passports (e.g. through QR codes; Smart tags etc.) is a key mechanism to capture this vital information
  - Wide-spread implementation of digital material passports would enable manufacturers to more easily recover, re-use and recycle valuable resources.

- Scaling up Industrial Symbiosis using Digitisation
  - Real-time digital marketplaces for production waste could enable diverse forms of industrial symbiosis (by-product exchanges and resource sharing) across industries
  - Linking up Industry 4.0 systems and internet-connected technologies is central to creating real-time digital marketplaces for waste
  - Scaling up implementation of real-time digital marketplaces for waste requires overcoming challenges associated with inter-operability between Industry 4.0 systems, standardisation, data security, and maintaining system stability ICT systems are interconnected.

- Circular Metrics and Mapping Tools for Manufacturers
  - Currently there are a plurality of methods used by industry to measure their circular performance - making it challenging to gauge and compare the actual progress made in implementing circularity across companies within an industry and between industries
  - Measuring progress in the circular economy requires standardised frameworks and indicators based on life-cycle analysis, which takes into consideration resource flows from raw material extraction, design, distribution and multiple use-phases to ultimate disposal at end of life
  - New measurement frameworks and digital tools are needed which can be seamlessly integrated into manufacturers' existing reporting and monitoring frameworks which account for the environmental, social and economic impacts of circularity and consider a wide scope of resources – including materials, energy and water.

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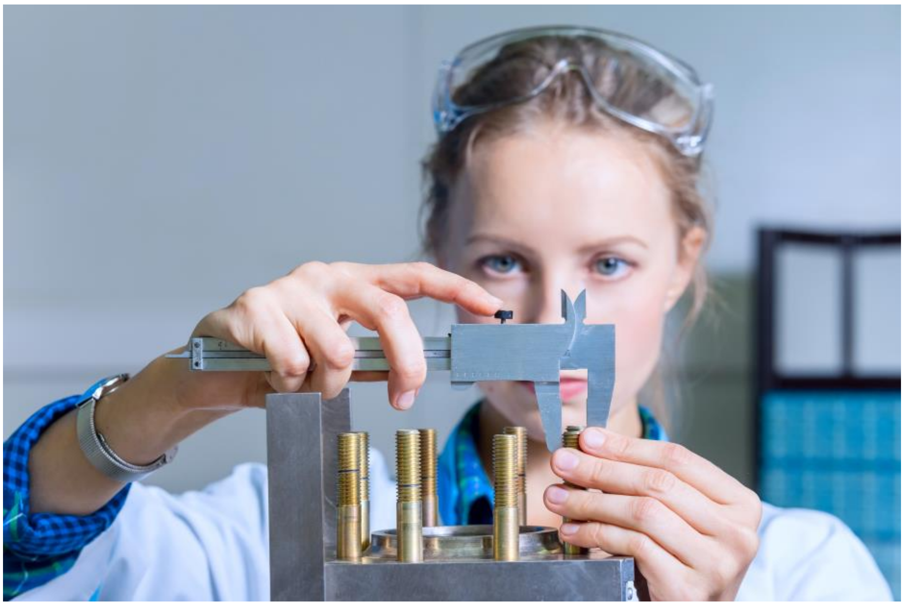
- Innovative processes and systems for sustainability in terms of energy and resource consumption and impact in the environment
  - Design aimed at manufacturing, assembly, disassembly, remanufacturing, reuse and recycling
  - Recyclability of new materials
  - Hybrid processing strategies for minimum resource consumption
  - Reduction of the carbon footprint of production processes based on complete life cycle information: lower consumption of materials, energy, lubricants, etc. and reduction of generated waste.

5.6 Customer-based Manufacturing



Involving customers in the manufacturing value chain will increase in importance, from product process design to manufacturing associated innovative services.

Research themes include the following topics:

- Modular systems, reconfigurable machines and processes for efficient adaptation to customer demands
- Customisation of products and processes
- Services for product operation (e.g. maintenance, reliability, upgrades), and end-of-life use (e.g. re-manufacturing, recycling, disposal). New tools must be provided for enabling and fostering the dynamic composition of enterprise networks, in particular SMEs.
- From user-centered design to user well-being design. The user is at the same time a customer, a citizen and a worker. The well-being of the user could therefore become a winning strategy. More detailed behaviour modelling can promote the development of innovative solutions, aiming at user comfort, safety, performance, style. Innovative solutions and new business models will be required to support a quick and dynamic response to market changes.

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ANNEX I

1 Aeronautic Sector

1.1.1 Grand Challenge

The main challenges of the aeronautical sector in advanced manufacturing focus on important reduction of recurrent costs and lead time. An ambitious evolution needs to be addressed in aspects such as integrated design and manufacturing development processes, composite and metal material processing, simulation and automation, digital transformation, monitoring and control, flexible manufacturing and assembly, and supply chain integration.

1.1.2 Gaps, Barriers and Bottlenecks to be solved

1.1.2.1 SHORT TERM

DEVELOPMENT OF NEW LOW COST/HIGH VOLUMEN PROCESSES:

New process systems allowing low cost manufacturing of structural aeronautical parts at higher production rates is the main objective at short term. Search into enablers for this kind of advanced processes allowing also a flexible or modular manufacturing is part of the focus, such are intelligent or flexible tools or ancillaries. Furthermore, the costs associated with assembly of aeronautical elements has a high impact on the aircraft final cost and so a greater integration of components at elementary part level is a necessity.

Along this line, technological developments related to more accurate and automated human-centered assemblies, integrating light automation and robots is a challenge.

MONITORING AND CONTROL

Safety associated with the product in the aeronautical industry is intrinsic to the existence of the business. The quality of the parts is a requirement for the entire production and safety elements have priority over any other consideration. Current process control means and non-destructive inspection of the manufactured elements is costly and time consuming

New generation design and production processes must combine specifics sectorial characteristics. To this end, active monitoring and full integration of the validation and verification systems throughout the product operating life is a need. Process parameter measurement in real time techniques, output predictability with control and action over inputs need to be developed.

Technologies that increase component´s safety and reliability range from more powerful and reliable simulation tools, on-line monitoring and control techniques and the integration of structural monitoring systems during the operating life of the aeronautical product, including measurements incorporated into automated and non-automated production, to mention the most relevant examples.

1.1.2.2 LONG-TERM

CONCURRENT DESIGN AND MANUFACTURING

The weight of an aircraft structure is an improvement target in terms of the reduction of emissions, consumptions and increasing the market share of all manufacturers. The need for all those companies that form part of the value chain is to develop technologies that generate less weight is a direct consequence. New materials under research (composites, metals, ceramics, multi-laminates, nano-composites, etc.) or their combination will demand the development of new production processes. Concurrent development of materials and processes is a must.
On the other hand, decreasing development times and increasing technologies´ maturity levels, before entering series production, is one of the main objectives for the aeronautical industry. Improved demonstration capabilities and simulation techniques and adequate training will be essential.

COMPLETE DIGITAL TRANSFORMATION

Even when partial integration of new ICT tools, as for instance improving the information given to operators to assure quick first time right execution is a short-term technology development, the complete digital transformation towards a virtual factory (and a virtual aircraft as a first step) is a long-term objective:

- To eliminate the risks generated by training personnel to undertake the assigned operations
- To have detailed information about the situation of production processes in real time, shortening the gap between production and management
- Optimizing preparation, downtime and tool changeover times
- Processes simulation (for improving ergonomics, etc.)
- Including active monitoring and control of processes
- End to end data backbone
- Intelligent operations coordination, including supply chain
- Tooling and parts control

2 Automotive Sector

2.1.1 Grand Challenge

The automotive sector landscape is rapidly changing, and must address the following global challenges: higher market and cost pressure, rise of product complexity by new mobility patterns and connectivity, and increasingly restrictive emissions and fuel-consumption requirements.

In terms of manufacturing, this implies developing systems capable of processing new advanced materials, as well as walking the path towards flexible, digital and sustainable production.

2.1.2 Gaps, Barriers and Bottlenecks to be solved

2.1.2.1 SHORT-TERM

PARTS INSPECTION AND MEASURING IN MANUFACTURING PROCESSES

In the automotive industry, strict product tolerances require comprehensive in-process control of components and final product's quality. To effectively correct deviations and guarantee that final product meets required tolerances, control must happen in real time. Artificial vision systems play a definite role in these control mechanisms and must allow image capture and analysis in real time.

In the automotive industry, continuous inspection will provide the data for a completely automated control, which will considerably increase efficiency and reduce the level of rejects, number of faulty parts and costs derived from inadequate behaviour in service. Apart from deciding if a part or assembled system meets required specifications, the inspection system must differentiate the faults, without any mistake, communicating their position and analysing possible sources of error, in order to be able to adopt the appropriate corrective measures. On the other hand, and with respect to functional behaviour, the surface inspection will undertake an increasingly important role.

DECREASE OF ENERGY CONSUMPTION BY PRODUCED UNIT

This is an approach whose aim is to reduce the amount of energy consumed by implementing measures and investments at technological and resource management level, with the objective of achieving a reduction in the energy used by each unit produced.

This focuses on getting the production plants to reach maximum energy efficiency. Thus, management systems aimed at reducing consumptions and emissions of CO2, automated energy management systems, and cogeneration and reutilization of waste for energy generation, will be used.

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Achieving this objective will require performing an analysis and simulation of the raw material and energy flow in each one of the production chain processes, which will contribute to minimising the environmental impact and focusing optimisation efforts on the processes and equipment that really have an impact on total energy consumption.

2.1.2.2 LONG-TERM

DEVELOPMENT OF IMAGE PROCESSING SYSTEM TO DETECT MODEL DIVERSITIES

The complexity of the production systems that derives from the diversity required by customers and by market demands, requires an increase in the inspection task. Being able to introduce detection systems and diversity confirmation into the different chain phases, requires fast and low cost processing solutions. These systems must also work in unfavourable environments: Electromagnetic fields, variable lighting, variable temperatures, etc.

The coexistence of photonics and robotics with advanced manufacturing processes in industrial environments, will permit monitoring large series of parts and parameters in reasonably short periods of time. The solutions of image processing and sensor systems are also cross-cutting for almost all sectors of industry, thus ensuring a high impact. They are also essential to achieve an increase in production ratios in the automotive sector.

AUTONOMOUS ROBOT OPERATIONAL NETWORKS WITH EMBEDDED INTELLIGENCE

The objective is based on developing a functional network comprised of flexible robots that can operate in changing environments to respond flexibly to new situations, and have advanced communication interfaces, such as voice recognition and visual recognition systems.

Adapting to the operator’s environment and adopting the necessary safety responses, whilst maintaining flexibility and the auto-adjustment of operational parameters, will optimise collaborative work, enabling more complex, dangerous or non-ergonomic processes to be addressed.

The development of integrated sensors, actuators and fast computing systems will ensure an effective co-existence between robots and workers. Repeatability and auto-calibration, as well as easy programming of robot activities, are key points for the evolution of robotics towards the required production environments, and their smooth incorporation into existing manufacturing lines.

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3 Consumer Goods Sector

3.1.1 Grand Challenge

The challenges of the consumer goods sector related to advanced manufacturing technologies focus on the following points: high rate production of customised products, incorporation of intelligence into the product chain by means of information management, implementation of user-guided creativity and innovation, integration of new materials and nano-intelligence, and green production chains for sustainable products.

3.1.2 Gaps, Barriers and Bottlenecks to be solved

3.1.2.1 SHORT-TERM

MATERIALS AND TECHNOLOGIES FOR DIGITAL MANUFACTURE OF COMPONENTS (EG: AUTOMATIC 3D PRINTING)

The eruption of additive manufacturing technologies into the field of prototyping is giving way to new forms of manufacturing, which, in the mid-term, must tend to integrate different systems and offer the possibility of working with practically any materials/structures.

In order to be able to work at relatively reasonable costs in functional products, further to conceptual models, an effort must be made to adapt/modify materials for their use in additive manufacturing systems, either syntherising, FMD or others, offering the end user the possibility of using practically any type of material or combination of materials.

Another possibility is the functionalization of materials used in additive manufacturing for special applications, increasing their possibilities of use. The development of builders that permit a local improvement in deposition precision or modification of the properties of the same material in different product areas is also an important field.

ADVANCED VALUE CHAIN INTEGRATION SOFTWARE, INCLUDING DEVELOPMENT OF COMPETITIVE INTELLIGENCE SYSTEMS BASED ON KNOWLEDGE OF THE MARKET AND OF THE CUSTOMER

Based on the possibility of companies integrated in the value chain exchanging data, the challenge lies in offering total integration from design to the point of sale, so that it is possible to generate feedback with a view to redesigning or readapting products/processes.

In this context, it is essential to capture knowledge from the market and from the customer. This is achieved by watching over the environment, which results in different processes: source management (search and update), tool management (definition and adaptation), methodology definition (routines, procedures, formats), and the categorisation, protection and dissemination of information.

This information contains the explicit knowledge of the environment available to the company, and which, when it reaches its addressees, becomes tacit knowledge, that is, knowledge that can promote programmes and projects that adapt and improve production processes.

3.1.2.2 LONG -TERM

DESIGN SYSTEMS THAT INCORPORATE GEOMETRY, MATERIALS, THEIR TECHNICAL CHARACTERISTICS AND COSTS. NEW CAD SYSTEM GENERATION. DESIGN FOR MANUFACTURING.

Design systems in the consumer goods sector are essential. At the present time CAD systems only contemplate geometry but they are far from providing an integral solution to the process that goes from the design to the manufacture of the product.

The future generation of design systems will be based on the concept of design for manufacturing, because of which, the CAD system will not just be taking into account the product geometry, but also the materials that make them up, the costs entailed, the technical characteristics that influence the manufacture, and the parameters of the machines/systems they will be manufactured with. Simulations of the product/process and of the human being-product behaviour will be obtained. A step further would even give rise to the integration of marketing decisions. With this future generation of design systems, the long-awaited Business Acceleration will be reached.

ADAPTABLE, NETWORKED AND KNOWLEDGE-BASED DIGITAL MANUFACTURING DEVELOPMENT

Factories of the future with a great variety of sophisticated consumer goods must offer a flexible and rapid production capacity, with controlled variability thanks to advanced automation. This guarantees energy-efficient, reliable and cost-effective production. Assuring optimal execution “the first time”, by improving the information given to operators relating to the manufacture or through other means, is a way of improving the current productivity. That is why the integration of new ICT tools is a technology development line to be deployed with different approaches and objectives:

- To eliminate the risks generated by training personnel to undertake the assigned operations
- To have detailed information about the situation of production processes in real time, shortening the gap between production and management
- Optimizing preparation, downtime and tool changeover times
- Improving ergonomics

Furthermore, exchanging data between companies in the value chain must permit total interoperability between both design and manufacturing systems. Collaboration and connectivity will provide an enormous amount of data, so those companies that carry out their analyses in real time will have a competitive advantage. Beyond integrated sensors and systems, the tendency is to interact in two directions with real objects and global scale systems, through a variety of application fields and interlocutors. This will be done in a safe manner and thus the Internet of Things will be constructed.

4 Capital Goods Sector

4.1.1 Grand Challenge

The Capital Goods sector faces 3 major challenges with respect to manufacturing; reduce the lead time from design to delivery with higher requirements of safety sustainability and zero defects, produce sustainably green manufacturing systems and assure the connectivity of the machines into highly complex cyber-physical manufacturing systems.

4.1.2 Gaps, Barriers and Bottlenecks to be solved

4.1.2.1 SHORT-TERM

GREEN MANUFACTURING SYSTEMS

The impact that companies have on the environment must be reduced and natural resources protected, more so in the European Union, which is deficient in natural sources of critical materials. The efficiency of capital goods not only affects their contribution to global warming or the emission of CO_2, but also the reduction of cost factors such as energy and raw material.

The management of the material and energy flow throughout the lifecycle means monitoring and optimising consumption in each and every one of the phases of the manufacturing chain.

Concepts around manufacturing with zero defects undoubtedly contribute to a reduction in the number of faulty parts, and consequently, to maximising energy efficiency, the use of equipment and of material resources.

SERVICE DEVELOPMENT FOR INTELLIGENT MANUFACTURING

We are witnessing the emergence of a new era in production technologies, where machines and processes are increasingly influenced by information and communication technologies (ICTs).

Cyber-Physical Systems (CPS) are collaborative computational elements that control physical entities, such as machine tools, assembly lines or other types. These CPS can interact and intercommunicate to optimise different aspects of the manufacturing process. But they are also extremely useful to provide operators with strategic information, at the right time and in a

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friendly manner. This will enable more effective decision-making and will contribute to the dissemination of knowledge at company level.

The manufacturers of machine tools demand the development of multi-variable modelling and simulation tools, with capacity to use advanced cloud computing, eliminating the need for licences and with real time access to equipment behavioural data through integrated sensor systems.

4.1.2.2 LONG-TERM

NEW FUNCTIONALITIES BASED ON SURFACE MODIFICATION

The increase in precision of manufacturing systems and the growing proximity between manufacturing and the micro/meso-scale, provide product designers with the capacity to afford enhanced functionalities based on surface modification, micro-texturing or advanced coatings.

These functionalizations can be achieved based on physical phenomena (additive manufacturing, micro-machining laser technologies, micro-milling, water jet, additive manufacturing, 3D printing or PVD coating (or based on chemical phenomena (coating by CVD, sol-gel, etc.).

Apart from developing robust processes from the viewpoint of their industrial scale-up, equipment must be developed that permit applying these surface modifications at macro-dimensional level, in many different products and industrial sectors, in a time-efficient and economical manner.

Efficient functionalization must be accompanied by the development of the necessary simulation models, foreseeing the behaviour that the system is going to have, once functionalised, or with the capacity to modify the process parameters according to the effect sought.

SYMBIOTIC HUMAN-ROBOT INTERACTION

Symbiotic and immersive collaboration between robots and humans in production environments will undoubtedly lead to the development of more efficient and flexible manufacturing companies. However, the aspects of cooperation, overlapping and safety in the industrial environment, as well as the advanced computational and sensorial processing algorithms have not been sufficiently developed to guarantee safe and seamless cooperation at manufacturing plants.

Manufacturing companies focus on unifying the work space of human beings and robots, but this requires the robot design to be safe and trustworthy, with integrated control and intelligence. To achieve the necessary capacities for the robots to be able to interact and cooperate with humans, self-learning strategies will be decisive.

5 Railway Sector

5.1.1 Grand Challenge

The main challenges of the railway sector in the field of advanced manufacturing are in line with the objective of achieving intelligent, safe, faster, efficient and sustainable transport, and they focus on 5 areas: integration of modular systems, interoperability of equipment, efficiency in the use of resources, processing of lighter materials and use of ICTs and electronics to add intelligence to the processes.

5.1.2 Gaps, Barriers and Bottlenecks to be solved

5.1.2.1 SHORT-TERM

PRODUCTION AIMED AT SUSTAINABLE TRANSPORT

Improving the efficiency of railway capital goods (rolling stock and infrastructure systems) is a basic objective that leads not only to a decrease in energy consumption per passenger unit or transported ton, but it also contributes to improving competitiveness of railway transport and improving the carbon footprint. Building on the fact that this mode of transport generally brings lower carbon footprint, a faster railway transport system will result in mode change and passenger and cargo migration towards rail, hence again lowering the carbon footprint caused of other, less efficient, modes of transport.

The integration of the lifecycle and recyclability variables from the design, production, operation and maintenance phases of railway material favour investments in control and optimisation of energy consumption throughout the value chain.

The incorporation of lighter materials is a consequence of the need to reduce energy consumption. Passenger comfort is an important conditioning factor when designing rolling stock, and vibrations are a field where manufacturers must seek alternatives with less repercussion and absorption of tension and stress.

The challenges mentioned in the field of materials have a direct impact on production means.

PRODUCTION AIMED AT INTELLIGENT TRANSPORT

The tendency towards repetitive manufacturing and modularisation in the railway sector leads to production management environments that are new for this industry: the potential of big data offers enormous possibilities, considering the product lifecycle.

Cyberphysical systems (CPS) or electronic sensors for instrumentation and control of operations are devices that will be integrated into production processes. They will also be increasingly integrated into the actual railway capital goods (rolling and fixed stock), so that they will facilitate

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functionalities and improve the actual railway transport operation management. Up to the level of the highest grade of transport automation – driverless operation.

Bearing in mind that the average life of rolling stock is around 40 years, the analysis and cost of lifecycle mean that simulation and modelling are vectors for development.

Like capital goods manufacturers, railway manufacturers also demand the development of multi-variable modelling and simulation tools, with the capacity to use advanced cloud computing.

5.1.2.2 LONG-TERM

PRODUCTION MODULARISATION AND ORGANISATION

The traditional production organisation and manufacturing model in the industry of railway materials has been and is very conservative. There are few rolling stock integrator constructors, with a reduced supplier base, which normally have to attend to one single railway operator. In this sense, the vertical integration of constructors has prevailed and the use of multi-platform modular technological solution was not the norm. This tendency is changing.

The use of the aforementioned multi-platform solutions entail important challenges in the manufacture of railway structures. Being able to develop more accurate and reliable welding systems for light materials, self-adaptable tools for changing models and automated forging processes for new alloys will be essential.

SYSTEM INTEROPERABILITY

Technical specifications for interoperability (TSI) are an instrument to define harmonised technical specifications for equipment, railway systems and transport operations at a European level.

Defined collectively by technicians and experts from all over the EU, the conformity of railway equipment and systems to the TSI has the virtue of granting unique certifications for the totality of the European interior market, so the possibilities of applying economies of scale in the manufacturing phase automatically increase. The increase in units to be produced of one same model will entail the automation of the processes, and the adaptation and use of certain man-machine-robot collaboration technologies, which are already being applied in the automotive sector.

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