Factories 4.0 and Beyond

Recommendations for the work programme 18-19-20 of the FoF PPP under Horizon 2020

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1 Introduction

EFFRA is preparing for its strategic discussion with the European Commission on the 'Factories of the Future' work programme 2018-19-20, covering the three last calls under Horizon 2020.

‘Factories 4.0 and beyond’ is providing a set of recommendations to support this discussion through a set of key priorities and research headlines

The key priorities and research headlines described in this document are heavily supported by the vision laid out in the Factories of the Future 2020 (FoF 2020) roadmap which is the basis of the contractual arrangement for the Factories of the Future PPP.

Although submitted to the European Commission at the end of 2013, the FoF 2020 roadmap contains many pointers to concepts that are heavily promoted under the name ‘Industrie 4.0’. This is not surprising since the ‘Industrie 4.0’ initiative was created during the same period as the compilation of the FoF 2020 roadmap. Even at the start of the FoF PPP in 2009, many of the items that are now strongly promoted as ‘Industry 4.0’ were important elements of the first FoF projects. Building upon this solid basis and upon a close dialogue with industry and academia, the introduction of existing and advanced ICT technologies in manufacturing has continued to be a crucial aspect of the FoF PPP, while going hand in hand with advancing the industrial state-the-art in areas such as material processing technologies and mechatronics systems.

In order to stress this strong relation and coherence, this document carries the title ‘Factories 4.0 and beyond’.

‘Factories 4.0 and beyond’ indicates how the FoF PPP 18-19-20 work programme can further implement this vision in synergy with the ongoing waves of ‘Industrie 4.0’ while building on the past and ongoing achievements of the FoF PPP.

This document is the result of processing the outcome of preparatory workshops at EFFRA, public workshops and a publication consultation carried out in spring 2016.

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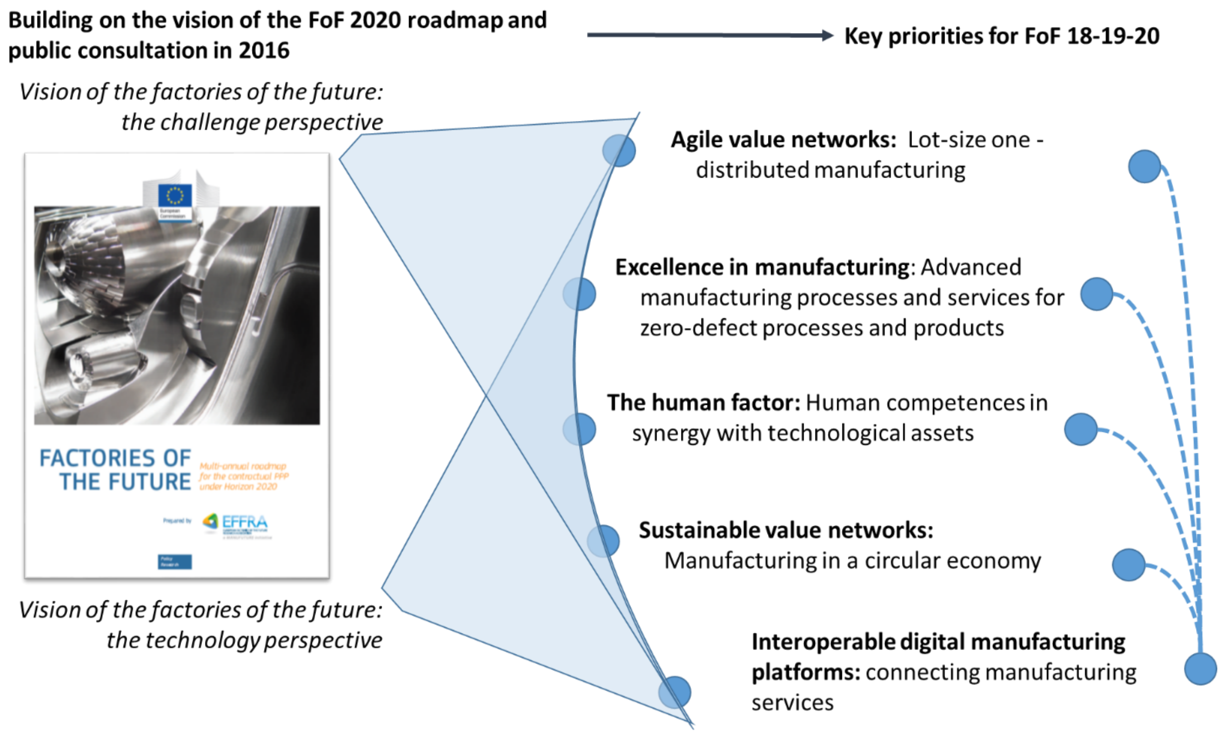
2 The 5 key priorities for the FoF 18-19-20 Work Programme

The following set of key priorities describe the main focus areas and targets for the FoF 18-19-20 Work Programme:

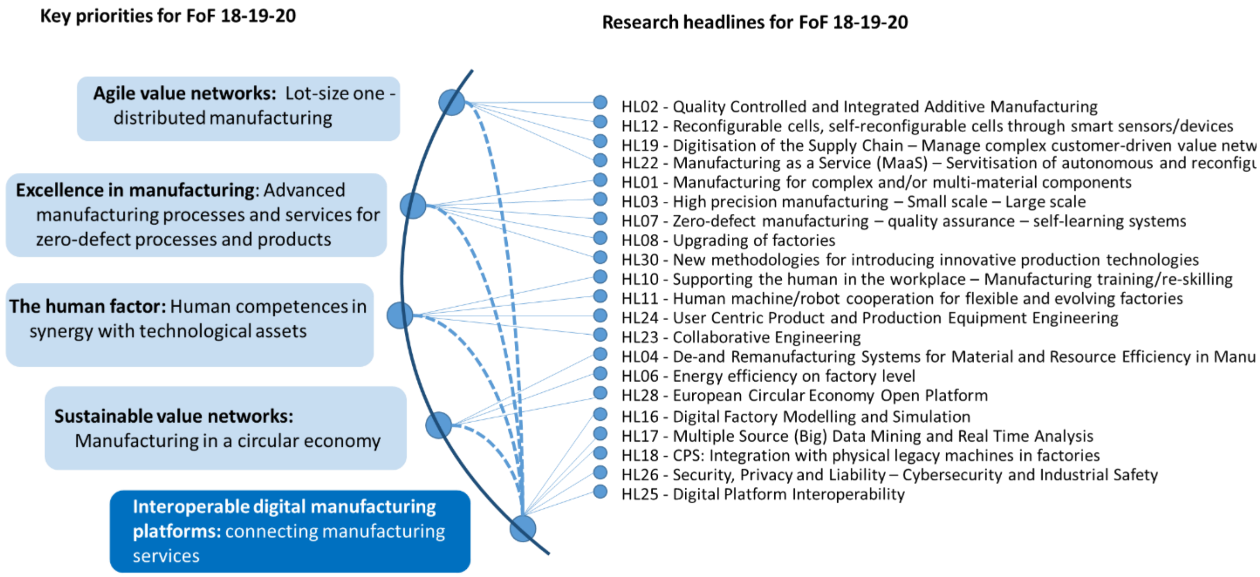
- **Agile value networks**: Lot-size one – distributed manufacturing
- **Excellence in manufacturing**: Advanced manufacturing processes and services for zero-defect and innovative processes and products
- **The human factor:** Developing Human competences in synergy with technological progress
- **Sustainable value networks**: Manufacturing driving the circular economy
  and
- **Interoperable digital manufacturing platforms:** supporting an eco-system of manufacturing services

Digital platforms play a supporting role in the achievement of the other key priorities. The key priority (KP) 'Interoperable digital manufacturing platforms' therefore plays a pivotal or horizontal role.

As mentioned in the introduction of this document, the key priorities are heavily building on the vision laid out by the FoF2020 roadmap.



The key priorities are described in the following sections, including their relation to the FoF 2020 vision and pointing to the more detailed description of research headlines.



Although the research headlines are linked to one key priority in the above illustration, they have in any cases strong relations to other key priorities.

In this following sections, more detailed description of the research headlines are included.

Note with respect to standardisation: Many of the key priorities and research headlines described in this document have in some way to do with standards (de facto standards, de jure standards, standards in the making). In general, FoF projects are not developing standards, although projects may generate findings that can be used to shape standards. Every FoF project is however assumed to take into account existing standards or ongoing standardisation activities in order to assure the industrial relevance and facilitate the uptake of project results. The same applies for regulatory aspects.

2.1 Agile Value Networks: Lot-size one and distributed manufacturing

The essentials (building on the vision of FoF 2020)

Agile value networks design, manufacture and deliver innovative products with a high degree of personalisation.

Robust manufacturing methods for manufacturing these products are not fully developed or deployed. Further research and innovation is needed to ensure that novel and robust manufacturing processes can efficiently support the production on a large scale of novel products for a wide range of applications.

While the need for sustainability is pushing for an extension of the life cycle, not only of products but also of the factories and capital equipment, factories are strongly supported by software, which can easily sustain high frequency of renewal and by processes and systems. Hence, upgradable, evolvable machines, cell and plants are necessary for flexible and responsive manufacturing. New organisational approaches and tools are required for manufacturing a mix of different products within the same cell/line/plant, optimising the internal and external logistics (including the supply chain) which often becomes the real obstacle when very flexible production capability is available.

'Thinking outside of the box' is not only required for generating technological innovation, it is also required for generating new approaches to operating supply chains and addressing markets. Through customer collaboration, ICT solutions enable extraction of customer and after-sales information and use this information to develop personalised and customised end-products of the future.

Main recommendations for FoF 18-19-20

The FoF 18-19-20 work programme should focus on:

(In Word or pdf: Click for further details of the headline, Alt arrow to come back in the document)

- Quality Controlled and Integrated Additive Manufacturing
- Reconfigurable cells and self-reconfigurable cells through smart sensors/devices
- Digitisation of the Supply Chain – Manage complex customer-driven value networks
- Manufacturing as a Service (MaaS) – Servitisation of autonomous and reconfigurable production systems

More references to FoF2020 vision (extracts from FoF 2020 roadmap)

FoF2020Quote-C 1: Personalised products: "Global competition requires the launch of new products with a shortened commercial life cycle and with a high degree of personalisation for adapting to individuals biometric parameters or for satisfying unique users' preferences. On the other side, sustainability is pushing for an extension of the life cycle itself. This dilemma can be solved by highly personalised products through software functionalities, which can easily sustain high frequency of renewal, or by the design of products, processes and systems that allow the sustainable re-manufacturing and materials recycling."

FoF2020Quote-T 1: Advanced material processing: "Innovative products and advanced materials (including nano‑materials) are emerging but are not yet developing to their full advantage since robust manufacturing methods to deliver these products and materials are not developed for large scale. Research is needed to ensure that novel manufacturing processes can efficiently exploit the potential of novel products for a wide range of applications."

FoF2020Quote-C 7: Flexible, evolvable and responsive factories: "Upgradable, evolvable machines, cell and plants are necessary for flexible and responsive manufacturing. New organisational approaches and tools are required for manufacturing a mix of different products within the same cell/line/plant, optimising the internal and external logistics (including the supply chain) which often becomes the real obstacle when very flexible production capability is available."

FoF2020Quote-C 17: The social aspects of local manufacturing: "In the near future, enterprises will have to seek production sites in places of high population density. Accelerated population aggregation in urban regions will affect citizens living close to manufacturing plants. Consideration of social responsibility to local environments is increasingly important and needs scientific answers as to how to make manufacturing plant location economically profitable with respect to energy demands, quality of living, natural resources, and safety."

2.1.1 Quality Controlled and Integrated Additive Manufacturing (HL02)

The challenge/vision

Additive Manufacturing (AM) has seen increased uptake because of factors such as design benefits and manufacturing flexibility for high value added parts and products. These benefits do, however, rely on a level of quality regarding material, geometry and surface finish where significant challenges still remain. Because of the nature of the layered build up in AM, there is potential for predictable and unpredictable defects to compromise material properties. The issues surrounding 'lot size of one' manufacture can also be addressed using the flexibility of AM both in design and manufacture. This is also compromised in a technical and commercial context if quality issues remain because multiple build failures are currently commonplace.

AM processing using powder bed based approaches is limited to the bed size, with limitations around hybrid build approaches due to equipment architecture. The solution of creating larger machines is not always economical or practically viable. Hybrid fabrication processes using multiple AM and other net shape technologies, such as casting, near net shape forging and hot isostatic pressing (HIP), followed by eg. a thermal treatment, assembly or joining stage, will address this issue whilst minimizing material waste.

There is therefore, a need for AM systems that incorporate quality approaches such as in-process, in-line and in-situ non-destructive testing, including addressing metrology issues that often occur due to distortion. The combination of optimised multiple near net shape processes to create component or component systems taking into account economic and sustainability issues will also stimulate a step change in the adoption of AM.

Specific technological (or non-technological) enablers or solutions that need to be addressed by the research or innovation activities.

Projects should address the quality aspects surrounding AM covering capability, stability and 'right first time manufacturing'. It is envisaged that several of the following areas will be covered:

- Hybrid AM processing including multiple procedures in one system e.g. processing, NDT, metrology, and finishing.
- In-process monitoring, feedback and control, in-line non-destructive testing and/or in-situ analysis on AM product.
- Direct link between material recycling, and further AM or other process, involving a digital approach.
- Enrichment of existing commercial CAD-CAM Platforms with new plug-ins and add-ons supporting the integration of AM processes and equipment.
- Multi-scale simulation, multi-physics simulation of the AM process, dynamic simulation of the whole AM system to aid optimal manufacturing performance from early design phase and avoiding costly trial and error runs.
- The prediction and minimisation of distortion, facilitating accurate geometrical prediction following post processing steps.

- Fabrication of components or systems using more than one near net shape technology, including AM, casting, near net shape forging, HIP, etc. that includes some form of joining or fitting. This would probably involve a reduction in part count.
- Initiatives to improve the interaction between humans and machines particularly in the area of CAD and its relationship with CAM.

Projects must include at least two different types of demonstrators in real industrial settings in order to show the industrial viability of the solution.

Expected impact

The developed industrialisation effort should lead to impact in the following terms:

- Improved product quality by 20%.
- Improve 'right first time' capability by 50%.
- Increased robustness of AM-based processes (%)
- Increased resource efficiency (%)
- Increased energy efficiency (%)
- Increased productivity (%)
- High value added component manufacture through multiple net shaping techniques.
- Hybrid machines that include AM processing and multiple quality systems.

2.1.2 Reconfigurable cells and self-reconfigurable cells through smart sensors/devices (HL12)

The challenge/vision

Agile manufacturing is supported by factory floors that are composed of manufacturing cells that are reconfigurable and/or self-reconfigurable, taking advantage of modular system building blocks. This required the introduction of IIoT-capable "agnostic" smart sensors which can be easily configured, combined and adapted to any specific application. Legacy hardware needs to be 'smartified' by intelligent combinations of existing communication technologies, such as reliable wireless communication technologies, and the distribution of computational capabilities.

Technologies should increase the Increase self-x capabilities of equipment: self-description, self-awareness, self-management, self-healing, self-correction and auto-discovery to enable self-(re)configuration. Additional decision making needs to be supported by intuitive data and information and its visualization.

Resilience, safety and security of cells needs to be ensured, while excluding disturbance of machine to machine communication

Specific technological (or non-technological) enablers or solutions that need to be addressed by the research or innovation activities.

- Use of established standards regarding communication protocols and interfaces
- Introduction of semantic modelling and knowledge management and sharing to enable the capture and reuse of information for (re)configuration
- Application of matching algorithms to find similarities to enable self-learning and rule based decisions, autonomous decision and decision support in near-real-time
- Development and deployment of connected smart sensors and virtual sensor networks
- Implementation of state of the art and new security mechanisms to cover cybersecurity concerns
- Redistribution of control capabilities into new building blocks of the system architecture
- Advanved communication, configuration and control paradigms by applying service oriented approaches
- Reconfiguration and redeployment of functional capabilities for smart devices and smart sensors
- Adoption of mesh networking technologies and swarm algorithms to improve M2M communication and collaboration
- Quality of Services and Incident detection based on continuous monitoring of all system parts
- Smart combination of cloud-, fog- and edge computing to ensure scalability, flexibility and resilience

Focus on demonstration

Expected impact

- Increase flexibility for efficient and quick reaction to market demands
- Enable self-recovery and increased resilience in the case of incidents
- Advance towards “Zero Lead Time” thanks to agile cell (re)configurability
- Reduce ramp-up times of new manufacturing processes, through self-configuration and self-learning systems by 20%"
- Increase overall cost-efficiency of production by 20%
- Increase decision competence of workers by fact-based decision support

2.1.3 Digitisation of the Supply Chain – Manage complex customer-driven value networks (HL19)

The challenge/vision

Digitalisation of manufacture related business processes and functions has been ongoing, for decades, and stakeholders in value chains already have pyramids of layered information systems. The existence of software systems does not mean that networked businesses operate in seamless, transparent, and effective way. The following challenges can be identified:

- The so-called silo effect has not actually relieved as interfaces are only partially opened by vendor-lockin or country specific aspects
- Too many overlapping standards and vendor specific platforms make interconnections laborious to implement
- There is no single solution for all situations
- The industry needs good examples, informative experiences, etc.
- Businesses, products, processes, etc., are in continuous change

The evolving IoT, industrial internet/industrial data exchange, CPS, big data technologies and emerging enablers such as blockchain enable or promise easier connected digital value chains. The challenge is to significantly reduce quotation-delivery lead time. Next-day delivery, order and receive a car in 5 days, get a key part in manufactured by a supplier in 2 days, etc.

The objective is to change the rules of the game from economy of scale (by China) to economy of networking (by Europe) in which a small batch, lotsize=1 and completely customized products can be produced for the price of mass produced products. Every robot, CNC systems, 3D printer, can change over to another program within cycle time.

The challenge is to digitize and automate the quotation/order/logistic/payment transaction costs for small series/lotsize=1 from customer throughout the whole supply chain. Two parallel approaches (red/blue ocean strategies) are foreseen: 1) further evolve today's factory connections within value chains specific solutions that can be demonstrated to other value chains and 2) create smaller, local cyberised flexible "copy" factories (localized/metropolitan manufacturing) that produce locally close to the customer and transport information as design, production recipes and not parts and goods. In both cases standardized industrial data spaces should be developed/used.

Specific technological (or non-technological) enablers or solutions that need to be addressed by the research or innovation activities

- Integration of CPS (from M2M/IoT) and ERP (all up to webbased customer order systems) with simple apps on top of them
- One common view on actual situation by all distributed parties
- Create new models where product-owners/solution providers own the design and production recipes which they can have produced as manufacturing as a services. Here not the product is ship over long distance, but the (encrypted/copy-right protected) designs/recipes are digitally transmitted
- Industrial data space architectures and standards need to be realized
- Development of federative platform frameworks enabling proper exchange of data
- Open, transparent digital market places for ordering product, parts, components, or other systems validating security identity of supply and value chain products/components entities and agents
- Shared cloud/platform (single), or distributed technologies such as distributed ledger database technologies included proper security and data protection/share/stewardship over all parties
- Smart part/component/product embedded devices to inform actual status of items in value chain. This data should be applicable for lifecycle use of each individual product
- New algorithms to handle in the proper way the information collected, to support and optimise the decisions for the correct digitalization of the supply chain.

Expected impact

Projects should demonstrate that the project will have a positive impact on one or more of the following criteria:

- Integrated Management of Collaborative Manufacturing and Logistics
- Complete chain from customer order via ERP and CPS to manufacturing and delivery in significant (30% or more) less total order-delivery lead time
- Create the one common view over the complete chain for all parties and demonstrate better decision making (reducing the corrections on decision or decision on decision by a factor two)
- Simplify adaptivity of chain configuration using platforms and apps (change configuration e.g. in case of sudden unavailability, in min/hours/days instead of days/weeks
- Distribute digital data instead of transport of goods (30%+ less CO2 emission)
- Common architecture/standard for use in industry
- Increased supply network agility
- Cross-sectors synergies through management of complex customer-driven value networks

2.1.4 Manufacturing as a Service (MaaS) – Servitisation of autonomous and reconfigurable production systems (HL22)

The challenge/vision

The availability of flexible production technologies (e.g. Additive manufacturing, robotic, nano-technologies, etc.) provides new opportunities for engineering and manufacturing products and design innovative processes (e.g. FABs).

Cloud and IoT technologies provide full knowledge of status and behavior of assets and products, making possible a complete new way to monitor and control the reality inside and outside the plants' environment

This landscape requires a complete new approach in defining the actual concept of manufacturing and the role of collaborating partners (in a B2B environment).

In the new perspective traditional manufacturers make available their production capabilities and capacities to business partners to integrate their processes and create dynamically virtual factory value chains.

In Europe these new approaches need to be available and rewarding especially for SMEs fostering their aggregation and the creation of structured value chains involving multiple players where big producers can easily engage and integrate small players with specific skills.

Availability of "fluid" production environments able to overcome traditional flexibility and elasticity limitations, via high speed and seamless reconfiguration capabilities of production assets adapting to dynamic changes of production needs, will be the key enabler for provision of innovative, high quality and competitive products for more and more demanding customer.

Specific technological (or non-technological) enablers or solutions that need to be addressed by the research or innovation activities

In order to achieve a consistent approach to the industrial challenges, one or more of the following areas have to be addressed:

- Autonomous reconfiguration and planning systems able to provide the production assets optimal configuration. Such features are enabled by fully pervasive embedded system deployment via the CPS and IoT paradigms, inside a fully "Cloud-ified" environment
- Aggregation of information from the cloud to support evolving status of production process and monitoring of assets and products
- Market place of required or available production capabilities and/or capacities to optimize saturation of the assets, supported by punctual monitoring and visibility for each B2B partner, of each single part of the process
- Dynamic creation of supply/value chains incorporating all the phases of Product Life Cycle, involving stakeholders at production, design, maintenance and End-of-Life with robust business models, Level of Service definition, confidentiality and liability rules

- Manufacturing service platforms able to provide various services to support re-configurability of flexible (automated) systems, based on open standards
- Definition of sustainable business models for Manufacturing services providers and utilizers, including intellectual capital protection

Expected impact

Projects should demonstrate that the project will have a positive impact on one or more of the following criteria:

- Significant improvement of primary processes performances:
    - Production Costs reduction
    - Delivery time reduction
    - Time to market reduction
- Increased flexibility (product variants) and elasticity (production capacity) of production assets
- Demonstrated saturation of production assets leveraging re-configurability and capacity/capabilities marketplaces
- Participation of SMEs to enhanced ecosystems based on Manufacturing Services

Note: The difference in focus of this headline and HL 19 (described in section 2.1.3 'Digitisation of the Supply Chain – Manage complex customer-driven value networks (HL19)') should be seen as follows:

- 'Digitisation of the Supply Chain – Manage complex customer-driven value networks (HL19)') allows the full integration from the machine to factory to network, and allows to work both on the processes as well on the systems till delivery of product to the customer. It focus also on the delivery issue, new ways to integrate order management and to transform it in production order in a networked context. The last mileage problem is addressed, as well as the full integration towards the customer
- 'Manufacturing as a Service (MaaS) – Servitisation of autonomous and reconfigurable production systems' (HL 22) focusses on manufacturing, to have "pieces of the process" which are offered on continuous basis in order to address different production needs. The focus is on how to provide the service, creating a market place for manufacturing services.

2.2 Excellence in Manufacturing: Advanced manufacturing processes and services for zero-defect processes and products

The essentials (building on the vision of FoF 2020)

The holistic optimisation of performance in order to ensure both the required quality and sufficiently high productivity while guaranteeing cost‑efficient manufacturing is driving the introducing of new methods and process technologies. High-performance manufacturing process and equipment are the enabler for innovative and competitive products and solutions.

High‑performance production combines speed, precision, quality and reliability. This requires process monitoring and modelling or simulation approaches, associated with novel optimisation and maintenance strategies. Learning controllers adapt the behaviour of systems to changing environments or system degradation, taking into account constraints and considering alternatives, hereby relying on robust industrial real‑time communication technologies, system modelling approaches and distributed intelligence architectures.

Research and innovation for the Factories of the Future is not only a matter of developing and integrating novel technologies. Manufacturing challenges can only be properly addressed if the manufacturing community understands the mechanisms to create value. OEMs offer value‑added services (e.g. maintenance, upgrade) or even sell their 'products as a service'. Remote services improve equipment uptime, reduce costs for servicing while, increase service efficiency and accelerate innovation processes (e.g. remote update of device software).

Main recommendations for FoF 18-19-20

The FoF 18-19-20 work programme should focus on:

(In Word or pdf: Click for further details of the headline, Alt arrow to come back in the document)

- Manufacturing for complex and/or multi-material components
- High precision manufacturing
- Zero-defect manufacturing – quality assurance – self-learning systems
- Upgrading of factories
- New methodologies for financial & risk assessments of innovative production technologies

More references to FoF2020 vision (extracts from FoF 2020 roadmap)

FoF2020Quote-C 2: Increased product intelligence: Service provisioning and enhanced functionalities in future products will require the introduction of increased product intelligence, such as the increased use of embedded mechatronics in components, which will require the design and production methodologies to evolve as a consequence.

FoF2020Quote-C 5: Multi‑material and multi‑functional products: Over the next decade, for a wide range of complex products, the holistic optimisation of performance will push towards new multi‑material and multi‑functional solutions. This will result in a change in the manufacturing paradigm by introducing new methods and process technologies within the factory in order to ensure both the required quality and sufficiently high productivity to guarantee cost‑efficient manufacturing

FoF2020Quote-C 9: High performance and zero-defect manufacturing: High‑performance production combines speed, quality and reliability of existing manufacturing technologies. This requires process monitoring and modelling or simulation approaches, associated with novel optimisation and maintenance strategies. "

FoF2020Quote-T 2: Adaptive and connected smart systems: Learning controllers adapt the behaviour of systems to changing environments or system degradation, taking into account constraints and considering alternatives, hereby relying on robust industrial real‑time communication technologies, system modelling approaches and distributed intelligence architectures

FoF2020Quote-T 6: Increased services through connectivity: OEMs will be able to offer value‑added services (e.g. maintenance, upgrade) or even sell their 'products as a service'. Remote service management helps to improve equipment uptime, reduce costs for servicing (e.g. travel costs), increase service efficiency (e.g. first‑visit‑fix‑rates) and accelerate innovation processes (e.g. remote update of device software). Through customer collaboration future ICT solutions would enable extraction of customer and after‑sales information from sources such as the social networks and feed this information to develop personalised and customised end‑products of the future.

FoF2020Quote-T 19: Manufacturing strategies: Research and innovation for the Factories of the Future is not only a matter of developing and integrating novel technologies. Manufacturing challenges can only be properly addressed if the manufacturing community understands the mechanisms to create value. 'Thinking outside of the box' is not only required for generating technological innovation, it is also required for generating new approaches to operating supply chains and addressing markets

2.2.1 Manufacturing for complex and/or multi-material components (HL01)

The challenge/vision

The requirements of innovation and efficiency are pushing industrial manufacturing methods to a new stage, where novel materials and components with enhanced properties are required. Currently, polymers and polymer based composites are well recognized to provide strength, light weight, corrosion resistance, impact resistance, etc. which are highly demanded from advanced technological sectors such as automotive, aerospace, electronics, consumer goods and others. On the other side, metals and in particular new high strength alloys can also provide outstanding strength, even combined with lightweight, together with easier rework and recycling capabilities. Furthermore, new metals and new multi-material combinations can improve the functionality of parts by making feasible more complex designs (ex. large and slender designs) which cannot be obtained with current materials.

While plastic parts provide flexibility and low weight, metals guarantee the necessary structural resistance, resulting in a more favourable performance/cost ratio. For this reason, in assemblies based on polymer / carbon fibre composites with dissimilar materials, in particular with metal parts, each type of material can contribute with its unique properties and complement the properties of each other. Thus the necessity of combining plastics with metals, leads to the development of new techniques in high quality joints to develop multi-material components. Among numerous classical joining methods to attach plastic to metal in manufacturing industry, the most relevant and widespread are: adhesive bonding, mechanical unions, mould-in techniques as well as thermal joining methods. Improved properties and functionality which is achievable through multi-material selection and design also poses new challenges in terms of the adequate manufacturing processes (e.g. machining, forming, laser-based processes, hybrid additive/subtractive technologies, finishing technologies).

Research and innovation activities should aim at the better tailoring of (local) properties of (lightweight) components and the increase or their design complexity through more controlled and predictable innovative enabling technologies. Components can include also large parts and can be composed of existing and new materials, composites, ceramics, multi-material and intermetallic alloys, light weight alloys…

Specific technological (or non-technological) enablers or solutions that need to be addressed by the research or innovation activities.

- Dissimilar material joining, Advanced Forming technologies for getting new functionality, higher function density, better quality of goods
- Novel or optimized manufacturing processes which can deliver components integrating multi-material concepts and/or more complex designs in higher volumes
- Modelling and simulation capabilities of the manufacturing processes, including the joining of dissimilar materials
- CAx solutions allowing to exploit known information from the manufacturing phase into the design and analysis phases

- In-line process monitoring and metrology to follow all critical steps along the manufacturing chain (e.x. quality, energy, scrap…) as well as to provide inputs for robust and reliable control
- Integrate Life Cycle Analysis by looking at the use phase and end of life (disassembly and recycling) stage of the component
- Multi-scale integrated design of assembled or complex product for high tech and low weight multi-material structure
- Product-process optimal design for advanced products/new materials

Expected impact

- Improvement of energy efficiency of production or products by 25%
- Improve productivity by 25% (through reduced set-up time and change-over time)
- Reduce Production cost for multi-material components by 50%
- Shorter development times of complex and/or multi-material components by 50%
- Lightweight components target to have Net shape or (near Net shape) - minimize non-functional machining efforts. 50 % lighter and improved properties.
- Higher density of functionalities in components
- First time-right production
- Enable the adoption of advanced and new material in consumer and mass produced goods.

2.2.2 Large Scale High precision manufacturing (HL03a)

The challenge/vision

High value and extreme precision parts manufacturing, based on classical or traditional material removing techniques, require production systems that ensure the quality of the components all along the process. Those kind of very critical pieces have to be manufactured in machines that ensure the precision and final quality of the part from roughing to finishing tasks. The high-precision manufacturing solutions should ensure the precision, accuracy, productivity and overall key quality indicators to reduce global costs and maximize production systems behavior. Those aims are aligned with Zero Defect manufacturing approach that should be somehow interconnected with high-precision manufacturing.

Solutions for this kind of requirements were faced in the middle of last Century in the engineering field of ultraprecision manufacturing technologies. Those techniques demonstrated that ultraprecision was feasible with large budget projects. In this headline it is considered another point of view: high precision manufacturing scenario with cost efficient solutions thanks to plug and play devices that measure, correct, estimate and compensate the errors from machine and mechanisms giving them smartness and connectivity to make decisions in process for precision and quality assurance.

Two types of manufacturing approaches should be considered in here: One of a kind parts manufacturing and low batches production solutions:

- One of a kind parts, very high value single parts have to be manufactured into production systems that include from machine, tooling and fixtures, to traceable metrology; therefore the quality would be ensured in each one of the process steps.
- Low batches parts solutions are focused for quickly reconfigurable manufacturing processes where the precision and accuracy is ensured within very fast machine adjusting techniques and solutions.

Both approaches are focused to reduce production costs by new quality standards, through an increment of final parts precision, at least 50%, making use of machines and production systems in which cost and final price for end user will not be higher than 5%.

Sectors like energy (power generation), scientific equipment/infrastructures and special projects for aerospace, oil & gas, mining or construction machinery could be some examples of very high value single parts manufacturing. They are niche sectors where European machine tool manufacturers are quite well positioned but in order to ensure large term positioning, an increase on performance, quality, precision, productivity and functionalities is demanded. On the other hand, customized production solutions are oriented to low batches manufacturing and high precision parts, where automotive and aerospace sectors are the two main drivers. Nowadays the optimization of production costs come from global analysis of manufacturing chain, and minimization of parts cost usually comes from lean manufacturing approaches, and therefore highly adaptive manufacturing machines and systems to fit with low batches are demanded. This way, the quick response, reconfigurable and high precision manufacturing processes will give a cost efficient solution for this kind of sectors.

In addition to classical machining machine tools (like lathes, machining centers, large milling and boring machines, and all kind of grinding machines), robotics arms for new manufacturing functionalities could be also considered in this headine. The robotics technology is not considered here as a research area, only the increase of precision and accuracy thanks to similar solutions like those developed for machine tools. Those robots will be oriented to lower critical tasks, where thanks to precision and overall accuracy improvement they will be able to carry out some precise machining operations.

Summarizing, this headine should be oriented to increase the precision of machine tools and manufacturing systems, through cost efficient technology solutions implemented to ensure the quality of high value parts manufacturing (single or low batches), giving the required smartness to in-process decision making capability, towards precision improvement and quality control under zero defects scenario.

Specific technological (or non-technological) enablers or solutions that need to be addressed by the research or innovation activities.

The technological approach of this headine should cover next research and innovation activities:

- Modeling of machine tools behavior from a multiphysics and mechatronics approach, considering elastic response from static and dynamic point of view, thermal response under feasible boundary conditions and actuator/control law implementation.

- Multivariate error budget for gather all modelling activity (static, dynamic, thermal, control…) as a useful tool to determine the expected behavior of overall machine to improve quality of final system through iterations and designing trials.
- New methodology for precision machines with fast and accurate reconfigurability to adapt as quickly as possible to new parts references. Oriented as a response to the increasing demand of quickly reconfigurable machines for low batches based production chains. It should consider hardware and software reconfigurability from a machine and manufacturing line point of view.
- Calibration and metrology on-machine. There will be developed on-machine measuring devices with metrological traceable solutions. They would be a reliable input for axis errors compensation, machine monitoring and calibration, and machining process correction.
- Compensation of machine geometric errors and final manufactures part machining programs. Based on the measurements from on-board metrology systems, ad-hoc adjusted mathematical models and self-learning algorithms, the errors predicted and expected will be compensated, ensuring the final quality of machined parts. For errors out of machine kinematics, it could be considered all-new solutions to increase the degrees of freedom of the machine to compensate mainly the alignment and angular errors.
- Development of plug and play devices to increase the precision and functionality of the machines, in order to achieve a big step ahead in machine response (quality, precision, productivity), with very cost efficient solutions.
- Finally, and based on the information from models and experimental behavior, there will be developed a solution to close designing loop, and consider all life cycle assessment of the machine tool, with main attention to precision evaluation and quick reconfigurability.
- Improve simulations and CAx software for high precision planning of the machining strategy.
- Standardization is important, both in the part of the assembled elements (sensors, actuators, electronics), and in the receiving part, in this case the machine tool control CNC itself. Therefore, the work carried out in the headine will also focus on the development and/or assessment of incipient industrial standards for mechatronic devices in machine tool environment.

Projects must include at least two different types of demonstrators in real industrial settings in order to show the industrial viability of the solution.

Expected impact

- Development of new on-machine measurement and compensation devices to ensure the quality and precision of machine tools. Thanks to them, precision in final parts should be incremented at 50%.
- Very cost efficient new family of machine tools with high increase in available precision, reconfigurability and quality. Cost and final price for end user should not be higher than 5%.
- Cost reduction for precision machining solutions will allow a democratization of high performance mechanism in sectors where the cost is the first driver, bringing there an increase of energy efficiency from a better adjustment of mechanisms and sub-systems.
- Implementation of lean and cutting-edge manufacturing trends within automotive and aerospace industry, with high demand on precision parts machining with lower batches. But also at very high value parts manufacturing in sectors such as energy, scientific equipment/infrastructures and special

projects for large construction, where one of a kind production is demanded, with very tight precision and accuracy requirements.

2.2.3 Small Scale High precision (HL03b)

The challenge/vision

Many industrial demands with high societal impacts from the mass production in several domains, e.g. automotive and aerospace, microelectronics, telecoms, medical imaging, astronomy programmes, consumable and high-end equipment, are driving the improvement of manufacturing accuracy and fabrication of fine features. Typical applications include the mass-production of automotive components such as gears and bearings, smart products embedded with micro systems (e.g. micro-fluidic devices and sensors), and small and precision parts in high-value customized consumables. High precision, complexity and micro-features are the typical characteristics of these mass-produced components (typically in the size range of 100 x 100 x 100 mm^3). While in the same time, cost reduction is still one of the pending requirements even when they are used in customized end-products such as cars and watches. The design of the functional surfaces and the production of more and more miniaturized systems and components of novel ceramic or composite materials require a comprehensive understanding of the manufacturing processes and the constant adaptation to the ever-increasing market demands. In order to achieve both economic competitiveness and environmental benefits for European stakeholders, the following challenges should be urgently handled in this research headline:

- Industry scale and novel high-efficiency precision finishing manufacturing technologies (both novel concept of equipment and processes such as ELID-grinding, hybrid-machining, hard turning, SPDT, EDM, ECM etc.) for the machining of advanced materials e.g. hardmetals, cermets, engineering ceramics, ceramic composites.
- Holistic in-process quality monitoring and control,
- In-process evaluation of material properties and surface integrities, and
- Suitable supply chain and business model.

Specific technological (or non-technological) enablers or solutions that need to be addressed by the research or innovation activities.

The technological approach in this research headline should cover most of the following research and innovation activities:

- Development of novel high-efficiency precision and micro finishing tool/equipment (e.g. to replace the tasks of hard turning and grinding) for 3D/freeform fabrication,
- Development of novel metrology concept (such as direct-end point measurement, 3D spatial metrology etc.) to obtain sub-micron dimensional accuracy in the full tool working volume,
- Methods and technologies to carry out in/post-process quality control to ensure 100% quality assurance, and the implementation of new quality control protocols such as QIF(Quality Information Framework) in industry,

- Material and workpiece handling in the new process chain, especially for complex components with finished clamping surface in LOTSIZE 1 production,
- In-process evaluation of material properties and surface integrities,
- Development of suitable supply chain and business model to meet this paradigm shift in manufacturing process chain.

The research or innovation activities must include at least two different types of demonstrators in real industrial settings in order to show the industrial viability of the solution.

Expected impact

The mass-production and precision manufacturing of micro/meso and complex components is of strategic importance to the European stakeholders in the perspective of jobs generation, and the research addressed in this research headline should contribute to its competitiveness. The research or innovation activities are expected to

- enable a new generation of products with improved features,
- create new market opportunities,
- improve the competitiveness, and
- generate new jobs.

All of the following objectives should be achieved by the research or innovation activities:

- Economical realization, with low energy footprint, of specific functional and technical requirements of specified industrial case-studies.
- Quantitative improvement (>30%) of the capacity of European manufacturing industry concerning competitive manufacturing micro/meso (in the range of 100 x 100 x 100 mm^3) components and devices (in terms of complexity, dimensional accuracy, production throughput and cost etc.)
- Improving the technological base and the competitiveness of European industry, especially SMEs;
- Emissions reduction of the chemicals, hazardous materials, dust, waste etc. by at least 30% in comparison to the conventional industry practice.

2.2.4 Zero-defect manufacturing – Quality assurance – Self-learning systems (HL07)

The challenge/vision

Manufacturing industries are continuously facing the challenge of operating their manufacturing processes and systems in order to deliver the required production rates of high quality products, while minimizing the use of resources. Zero defects manufacturing (ZDM) is aiming at going beyond traditional six-sigma approaches.

Traditional six-sigma techniques show strong limitations in highly changeable production contexts, characterized by small batch productions, customized, or even one-of-a-kind products, and in-line/on-line product inspections. Innovative and integrated quality, production logistics and maintenance design, management and control methods as well as advanced technological enablers have a key role to achieve the overall production quality goal.

The main objectives of ZDM approach are to get zero defects in a production environment (i.e., to get it right at the first time), to achieve waste/scrap reduction, lower production costs, shorter production times, higher productivity & competitiveness, and last but not least, a higher resource& energy efficiency. All those goals should bring a significant competitiveness increase and job creation for the EU manufacturing industry.

Among the challenges that the ZDM approach brings to industries, it's worth to highlight the identification of error sources & types, the identification of most problematic phases within a LifeCycle Assessment (LCA) approach, the clustering of errors (and subsequent solutions) according to the most common levels in an industrial shopfloor activity, and finally, the development & implementation of suitable ZDM tools as solutions for the upstream generation and downstream propagation of production defects.

Regarding the above mentioned zero-defects levels, the ZDM paradigm in an industrial factory approach may be composed by several relevant fields & layers.

- Process level: on one hand, workpiece-fixturing-clamping, components & machine, manufacturing process (in where error sources are located and ZDM tools should be implemented).
- Multi-stage system level: on the other hand, interconnected manufacturing cells and shopfloor/workshop dimension, where data acquisition & processing, data monitoring, process prediction & optimisation become more critical.

Specific technological (or non-technological) enablers or solutions that need to be addressed by the research or innovation activities.

An integrated approach to quality, safety, maintenance, lead time and productivity is requested. It should be supported by:

Zero-defects manufacturing approaches at process levels (to identify error sources and to avoid error propagation downstream) such as

- Integrated machine, fixture, tool, workpiece modelling and simulation for quality deterioration prediction and associated maintenance planning
- integration of intelligent, autonomous, self–adaptive, self-powered and cost-effective sensors and actuators for process monitoring, control and quality management
- Process adaption by self-learning, quality and process data based modelling of process behaviour

- Robust automation of processes with input uncertainty

In-line quality acquisition, before, during and after the process, such as

- New measurement and inspection technologies and on-line material characterization and NDT
- Development and integration of in-line or in-process measurement and inspection techniques (NDT) and the use of modern sensor technologies that can remove the need for end-of-line inspection, without bringing significant in-process cost increases (cost-effective) or time losses (keeping productivity)

Data mining & data analytics through advanced sensing and integrated approach through the manufacturing chain, such as

- Strategies for optimally combining and harmonising heterogeneous data such as images, geometry (CAD, triangle meshes or point clouds) as well as numerical raw data, captured during the whole product-life-cycle (from design to manufacturing) for converting such data into information and knowledge
- Plug-and-inspect data gathering systems, based on auto-configuration of data exchange protocols and IoT solutions
- The statistical assessment of the variation of manufacturing quality, geometrical analysis and classification methods, and practices for estimating the effect of variation of manufacturing quality

Projects must include at least two different types of demonstrators in real industrial settings in order to show the industrial viability of the solution.

Expected impact

Dramatic enhancement of quality and reduction of waste by fully automated, intelligent and self-adaptive process control

- Improved overall equipment effectiveness.
- De-risking production installations
- Increased productivity on continuous manufacturing process change: 20% faster changing time on machines and resources
- Increased efficiency on preventive maintenance: 90% identification of errors, malfunctions or damaged parts thanks to predictive self-learning systems
- Reduction of programming of new manufacturing processes, through virtual commissioning and self-learning systems down of 20%
- Provide a technological, but also methodological approach to transform current plant into systems with self-learning capabilities
- Projects should integrate specific technology already present on the shop floor (e.g. automated lines, robots, power management, etc.) migrating overall production structure towards self-learning and self-optimizing new paradigms
- Projects must demonstrate the reliability of the overall systems and the implication of a failure or a degradation of their functions

2.2.5 New methodologies for introducing innovative production technologies (HL30)

The challenge/vision

More than 50% of the European industrial machinery is lacking state-of-the-art automation of production and quality control. Replacement factories are more likely to be built in upcoming markets than in Europe. At the same time, very promising new manufacturing technologies are not taken up and are lacking investment. As a consequence, European industry requires methods and approaches to upgrade its factories. Focus should be on

- supporting SMEs in upgrading their factories to manufacture new products in a cost-effective way.
- Facilitate the investment in and the uptake of new manufacturing technologies in industry

Specific technological (or non-technological) enablers or solutions that need to be addressed by the research or innovation activities.

- Development of suitable methodologies for more transparent and precise investment appraisals, financial viability analysis and risk analysis
- Modeling of uncertainty to support financial & risk assessment with integrated simulation capabilities and ability for adaptation on the basis of continuously updated data
- Creation of methods and tools for assessing and increasing the "investment readiness"
- Improving measurement and assessments of resource efficiency benefits, better consideration of efficiency gains in investment decisions
- Improving measurement and assessment of non-monetary benefits (flexibility, speed, reliability, resilience, networks) or costs (loss of human creativity and knowledge, decontamination of brown fields, cyber-risks, option values etc.) of the renovation of factories
- Improve understanding between technologists and investors, involving economists, social science, financial experts, business model experts
- Clarifying the role of public interventions
- Study of financial impact and the return on investment regarding regulatory issues and sustainability integrated into the new products and services offerings in the manufacturing sector

Expected impact

The main expected impact is to transform existing factories to excellent factories and boost the reindustrialization of Europe, while

- Improving allocation of financial resources
- Better, evidence based decision making
- Facilitating investments decisions and access to capital
- Lowering investment and innovation barriers
- Facilitating dialogue with investors
- Increasing training and qualification of personnel in industrial plants.
- Targeting skills shortage in current and new skills, knowledge and competences.

- Validating the uncertainty management in realistic business scenarios covering extended supply and value networks
- Renewal of EU-factory landscape, facilitating the uptake of innovative and sustainable manufacturing technologies

2.3 The Human Factor: Human competences in synergy with technological assets

The essentials

The next generation workforce is being raised in an Internet society and is accustomed to a vast range of smart devices and rich interaction techniques. At the same time, industry is undergoing a substantial digital transition which will change the role of humans and machines. A new distribution of tasks will require new skills and competences from the workforce – not only on the shop-floor. In parallel, technological progress has huge potential to adapt working conditions and make work both more attractive and productive – and finally safeguard the jobs.

Connectivity is inherent to the development of the future workplace. Future knowledge‑workers should interact dynamically and share tasks with smart manufacturing technology. Collaboration and allocation of tasks between humans and manufacturing technology should be done through appropriate and adjustable levels of physical and cognitive automation. Human capabilities should be enhanced e.g. by safe human–robot collaboration, mobile and location‑aware communication devices, and customer–worker collaboration capability. Within this context, manufacturing education and re-skilling has a key role in preparing humans for new approaches to knowledge communication, skill and competence development, and advanced training.

Main recommendations for FoF 18-19-20

The FoF 18-19-20 work programme should focus on:

(In Word or pdf: Click for further details of the headline, Alt arrow to come back in the document)

- Supporting the human in the workplace – Manufacturing training/re-skilling
- Human machine/robot cooperation for flexible and evolving factories
- User Centric Product and Production Equipment Engineering
- Collaborative Engineering

References to FoF2020 vision (extracts from FoF 2020 roadmap)

FoF2020Quote-T 7: Ubiquitous connectivity - 2: Connectivity is inherent to the development of the future workplace.

FoF2020Quote-C 12: Integrating human and machine intelligence through ICT - 1: Human capability and machine intelligence will be integrated within production systems that can achieve maximum efficiency as well as worker satisfaction. Research efforts should tackle social sustainability challenges at all levels of manufacturing industries. This effort will be economically very successful, while still improving corporate social responsibility, inclusive workplace design, and efficient use of ICT to leverage the competence of the European workforce.

FoF2020Quote-C 13: Integrating human and machine intelligence through ICT - 2: Future knowledge‑workers should interact dynamically and share tasks with smart manufacturing technology. Collaboration and allocation of tasks between humans and manufacturing technology should be done through appropriate and adjustable levels of physical and cognitive automation. Human capabilities should be enhanced e.g. by safe human–robot collaboration, mobile and location-aware communication devices, and customer–worker collaboration capability. Within this context, manufacturing education has a key role in preparing humans for new approaches to knowledge communication, skill and competence development, and advanced training.

FoF2020Quote-T 9: Tools for supporting the role of workers -1Workers' direct interaction with physical systems will enable processes that are real-world aware, event-based, and significantly more adaptive than today's processes, which will result in increased visibility, responsiveness, and safety in the workplace of the future

FoF2020Quote-T 3: Cognitive systems: Cognition-based intelligent features within machinery and robots will radically change their interfacing towards human operators in manufacturing environments. Machinery and robots will follow an intuitive cooperation and will use navigation and perception technologies to be aware of its work and of its environment.

FoF2020Quote-T 4: Ubiquitous connectivity - 1: Advanced machine interaction with humans through ubiquity of mobile devices and novel natural interaction devices will enable users to receive relevant production and enterprise-specific information regardless of their geographical location and tailored to the context and the skills/responsibilities they own. Interactions with ICT infrastructures and equipment will be intuitive and natural language-like

FoF2020Quote-C 17: The social aspects of local manufacturing: In the near future, enterprises will have to seek production sites in places of high population density. Accelerated population aggregation in urban regions will affect citizens living close to manufacturing plants. Consideration of social responsibility to local environments is increasingly important and needs scientific answers as to how to make manufacturing plant location economically profitable with respect to energy demands, quality of living, natural resources, and safety.

2.3.1 Supporting the human in the workplace – Manufacturing training/re-skilling (HL10)

The challenge/vision

The main challenge from the perspective of the humans in workplace is the rapid and continuous change of working environment in terms of economic, organizational and technological transformation. Workers will no longer perform their tasks routinely instead they will have to undertake varied and mostly unstructured tasks, depending on the needs of the dynamically changing production process. Teams should/will include flexible and remote ways of working and interacting with the systems as well as with other workers.

In the future, visual models of the production systems will allow employees to enlarge their feeling, comprehension and sense making. Employees will be able to interact with the models, to receive concrete feedback and to store their personals experience. The wealth of available experiences, sense making and stories will contribute to the creation of the individual employees and collective factory identity. This wealth and knowledge base will be retrieved, elaborated and exploited for reflection, learning and future evolution of production systems.

Specific technological (or non-technological) enablers or solutions that need to be addressed by the research or innovation activities.

- Visual and physical representations of Smart Production Systems supporting methods and tools to predict and evaluate their dynamic behavior and working conditions (such as noise and vibrations, environment, ergonomics and psychosocial factors), including humans in the loop (HITL)
- HITL modelling and simulation to support the participative design of organization, tasks, roles and responsibilities describe stationary and dynamic, regular and exceptional working conditions, including Smart and remote Working
- Novel modelling and prediction tools to encompass the roles and behaviors of employees whether they directly operate on the machines, in the control loop of the physical process (Human-in-the-Loop of Cyber Physical Production Systems, HiLCPPS), and whether they interact with applications of the digital factory that interconnect different machines and devices as nodes in a mesh (Human-in-Mesh of Cyber Physical systems, HiMCPS)
- Novel tools such as Augmented Reality adaptable to different environments and worker roles and activities not limited only to training and/or maintenance but also available in shop-floor operation
- Models for individual and collective sense-making, learning and knowledge accumulation
- Wearable embedded equipment wirelessly connected with the surrounding manufacturing environment for enhanced safety, workplace adaptation and ergonomics, worker's well-being monitoring
- Novel education and training paradigms (e.g. Teaching and Learning Factory) for continuous learning and re-skilling.
- Interconnecting workers with machines and processes and developing context-oriented services towards safety practices and decision making
- Enabling the worker to personalise the workplace and the offered tools for comfort and performance.
- Consider privacy issues when collecting human data.

- Reducing stress and uncertainty when adopting new technologies and processes through the utilization of modern VR/AR technologies.

Expected impact

- Improve well-being, human engagement and productivity in an increasingly automated context
- Address unbalanced working conditions, while providing productivity gains.
- Eliminating skill gaps and skill shortages that hinder the industry's innovation performance
- Including the "corporate memory" capturing knowledge model: Human embodied knowledge to be captured and to be passed to colleagues through training, for fostering the continuous learning and successful evolution
- Deploying new education and training approaches for developing skills and building competences through the seamless integration of innovation, education and training activities
- Increase the use of knowledge and involvement of senior employees.
- Increase manufacturing enterprises environmental and social sustainability performance tracking
- The proposed technical solutions are validated in an industry environment, and its methodology is applicable to a wide range of industrial areas.

2.3.2 Human machine/robot cooperation 'Cobots' for flexible and evolving factories (HL11)

The challenge/vision

The research on human-robot collaboration has largely focused on safety of humans allowing workers and robots to share space without fences. This has resulted in robotics systems which are safe to collaborate but are not truly collaborative. Additionally, the collaboration and safety has remained a local aspect addressing human-collaboration in few tasks or robotic cells in a defined space on the factory floor. This approach is not compatible with the reorganization of production spaces and to meet the changing demands of production and intra factory logistics. Moreover, most of the development in human-robot interaction (HRI) has remained focused around the industrial robotic arms and not much attention has been paid on developing novel robotic concepts which are inherently safe and collaborative.

Specific technological (or non-technological) enablers or solutions that need to be addressed by the research or innovation activities.

The design of human-robot systems shall go beyond the concepts of safety. Aspects of ergonomics, productivity, adaptability, acceptance and user experience must be considered as a whole while developing human-robot collaboration. The focus needs to be extended from individual user and individual robot collaboration to planning and implementing work environments where robots and workers function as members of the same team throughout the factory. The robots shall continuously evolve to demonstrate higher levels of perception and adaptability resulting in factories functioning like a harmonized organism with holistic cognition.

Aligned with this scope, research activities shall address a combination of at least three of the following areas:

- Extend the load capacity of collaborative robots (including the deployment of advanced grippers) while ensuring the safety, task ergonomics and scalability of the solution. The developments shall go beyond conventional robot design and consider the industrialization of recent developments in service robotics and mechatronics.
- Enabling the true mobility on the factory floor with mobile platforms and robotic arms, capable of not only navigating in dynamic production facilities but also accurate positioning for the final task execution.
- Implementation of novel artificial intelligence technologies capable of massive information processing and reacting in real-time to enable new levels of autonomy, navigation, cognitive perception and manipulation for robots, while integrating of humans in the process (e.g. prediction of motions, characteristation of processes and characterisation of capabilities of the worker (e.g. 'left- right handed' workers,…), learning from workers,…

The research and development activities shall engage the factory workers giving significant importance to human factors such as user experience, comfort, trust and feeling of safety in modern production facilities taking into account the age and gender aspects.

At least one demonstrator per area shall be delivered, excluding commercially usable prototypes.

Expected impact

The developments shall have substantial impact in the following areas. Not all impacts needs to be demonstrated on single demonstrator.

- Demonstrating a business case to bring back or keep production in Europe and thereby accelerating the reindustrialization of Europe.
- Demonstrating the 20 % increase in the productivity through full or semi-automation of manual tasks.
- A significant reduction in production reconfiguration time and cost.
- Introduction of new robotic concepts on the factory floor with feasible business cases.
- Qualitative and quantitative improvements in daily work of the factory workers.
- Strengthening the technological base of Europe by showing the increased global export of new production equipment and technologies.

2.3.3 User Centric Product and Production Equipment Engineering (HL24)

Note: This headline is much related to the headline HL 23 (described in section 2.3.4 'Collaborative Engineering (HL23)').

The challenge/vision

More and more IT tools used for product conceptualisation and design are opening to information and knowledge coming from inside and outside the companies, enabling new forms of open innovation and product co-creation, with a deeper customer engagement.

Techniques as Social Networks Analysis, Business Intelligence, Big Data and Sentiment Analysis, fostered by the tons of data generated by hyper-connected mobile IoT devices, can bring a new level of understanding and market / field knowledge. Data concerning emerging market trends, user preferences, as well as product failures and bad usages could be collected and analyzed in order to decide future products design & development, as well as to provide further services and experiences to customers after the sale. Aftermarket data can help in understanding middle life cycle product cost, maintenance issues, total cost of ownership and how this impacts on product desirability. From these data, designers and engineers will be able to define new forms of knowledge, for creating better products, more sustainable customer-oriented solutions, and more reliable systems, opening their innovation process to the market.

With the same techniques, data, information and knowledge can be scaled up also from production systems (shop floors, plants) to decision makers, thus enabling the re-design and re-development of agile configurable nodes, thus supporting more flexible, reliable, customized, efficient and effective systems.

In this, there is the need of new tools and solutions able to study and manage data coming from the field, both at shop floor level and after the sale, when the product is already in the customer hands.

Specific technological (or non-technological) enablers or solutions that need to be addressed by the research or innovation activities.

Projects must focus on the development of a comprehensive solution, made by a set of innovative and adapted techniques, methods and tools which should enable the following issues:

- Acquisition of both factual and sentiment feedback/data both before and after the sale
- Inclusion of data and information coming from manufacturing systems into design tools and practices, enabling an open innovative context, in which designers and engineers could develop more customized and sustainable products and solutions

Expected impact

- Improve design and engineering activities, reducing bad designs and warranty costs and making available more reliable solutions. Within applications in Business-to-Consumer (B2C) contexts, it is possible to expect at least a reduction of 30% of quality design costs. In Business-to-Business (B2B) contexts, we should expect a higher customer satisfaction and loyalty.

Generally greener and more innovative products and services should be made available, which could bring a sensibly grow in the market share. We can expect a double digit improvement, at least in niche contexts.

2.3.4 Collaborative Engineering (HL23)

Note: This headline is much related to the headline HL 24 (described in section 0 ‘

User Centric Product and Production Equipment Engineering (HL24)').

The challenge/vision

- It is about collaborative services in the factory for product and production improvement provided by an interoperable framework able to capture meaning, context and knowledge of information to be shared.
- Spread knowledge and awareness of design and engineering among several actors, inside and outside the company, from technicians, to production workers, from external designers, and the user
- Comprehensive harmonisation of the existing and new tools and methods and adaptation to specific industries (e.g. capital intensive industries, design-driven industries, etc.)
- Social dimension. Design and engineering – for products as well as for services – is a high knowledge content area, where companies need to understand how they could collaborate in a global scale, involving actors with diverse roles, competences, languages and cultures. Currently, there is a lack of rewarding mechanisms linked to co-operation. European workers and citizens need to be educated to recognize the importance and the business opportunities that can be obtained from intra and inter-organization collaboration. This could be an important way to increase the capability of understanding different business cultures and increase the knowledge sharing and creativity with global interconnected engineering teams

Specific technological (or non-technological) enablers or solutions that need to be addressed by the research or innovation activities.

- New application of existing engineering tools and methods as well as new approaches for collaborative engineering created and experimented in emerging contexts
- Big manufacturing companies should be asked to play their role as leading organizations, supporting and aligning the efforts of SMEs belonging to their value networks
- Methodological dimension. The diverse available methods and methodologies to cooperate are still unknown in many manufacturing companies, in particular to SMEs. For example, even if Concurrent Engineering exists from almost 30 years, a reference model supporting the implementation of suitable software tools for a collaborative engineering in a virtual enterprise is still lacking. There is still place to provide some new / adapted methodologies, for supporting a more effective collaborative design and engineering.
- Technological dimension. While ICT evolution is going fast, industrial users are still in trouble in finding and identifying the best applications for fostering real collaboration in their design and engineering processes. Some sectors call for some specific adaptations and guidelines in implementing software solution for collaborative design tasks.

Expected impact

- Reference of best practices need to be defined in specific industries
- Reduction of time-to-market of new products and services: 20%
- Reduction of development costs of new products and services: 20%
- Improvement of the design and development capabilities: 20%

2.4 Sustainable Value Networks: Manufacturing in a circular economy

The essentials

Global competition requires the launch of new products with a shortened commercial life cycle and with a high degree of personalisation. However sustainability is pushing for an extension of the life cycle of products. This dilemma can be solved by highly personalised products through software functionalities, which can easily sustain high frequency of renewal, or by the design of products, processes and systems that allow the sustainable re-manufacturing and materials recycling.

Process monitoring and control can provide support here, for optimising the performance and resource consumption on machine level and factory and supply chain level, where decision- support systems consider energy consumption globally. This includes selectively switching off systems and components, using smart sensor networks and energy-efficient scheduling approaches, reducing peaks in energy demand, recovering and reusing electrical energy from decelerating drives or process heat, etc. Process monitoring should also support the consideration of resource-efficiency in maintenance approaches.

Simulation and modelling methods and tools that consider resource consumption and emissions will have an impact both in the design and operational phase of manufacturing systems. Here, it is important to use life cycle analysis in order to avoid sub-optimisation and to promote transparency.

Optimal use of materials also involves increasing the deployment of near-net manufacturing processes, such as additive manufacturing, hereby reducing raw material consumption and allowing production of highly customised level design

Co-evolution of products–processes–production systems involves engaging traditionally separate industries involving physical exchanges of materials, energy, water, and/or by-products and requires an optimised interaction of manufacturing with transport and critical infrastructures

Main recommendations for FoF 18-19-20

The FoF 18-19-20 work programme should focus on:

(In Word or pdf: Click for further details of the headline, Alt arrow to come back in the document)

- De-and Remanufacturing Systems for Material and Resource Efficiency in Manufacturing
- Energy efficiency on factory level
- European Circular Economy Open Platform

More references to FoF2020 vision (extracts from FoF 2020 roadmap)

FoF2020Quote-C 1: Personalised products: Global competition requires the launch of new products with a shortened commercial life cycle and with a high degree of personalisation. However sustainability is pushing for an extension of the life cycle of products. This dilemma can be solved by highly personalised products through software functionalities, which can easily sustain high frequency of renewal, or by the design of products, processes and systems that allow the sustainable re-manufacturing and materials recycling.

FoF2020Quote-C 20: Monitoring for sustainability: Process monitoring and control can provide support here, for optimising the performance and resource consumption on machine level and factory and supply chain level, where decision- support systems consider energy consumption globally. This includes selectively switching off systems and components, using smart sensor networks and energy-efficient scheduling approaches, reducing peaks in energy demand, recovering and reusing electrical energy from decelerating drives or process heat, etc. Process monitoring should also support the consideration of resource-efficiency in maintenance approaches.

FoF2020Quote-C 21: Simulation and modelling for sustainability: Simulation and modelling methods and tools that consider resource consumption and emissions will have an impact both in the design and operational phase of manufacturing systems. Here, it is important to use life cycle analysis in order to avoid sub-optimisation and to promote transparency.

FoF2020Quote-C 22: Near-net for material efficiency: Optimal use of materials also involves increasing the deployment of near-net manufacturing processes, such as additive manufacturing, hereby reducing raw material consumption and allowing production of highly customised level design

FoF2020Quote-C 23: Synergy on process and supply chain level: Co-evolution of products–processes–production systems involves engaging traditionally separate industries involving physical exchanges of materials, energy, water, and/or by-products and requires an optimised interaction of manufacturing with transport and critical infrastructures

2.4.1 De-and Remanufacturing Systems for Material and Resource Efficiency in Manufacturing (HL04)

The challenge/vision

With the objective to increase material and resource efficiency (not focusing on energy efficiency) and contributing to the global human well-being, the European manufacturing industry should perform a significant transition from the traditional "take-make-dispose" approach, resulting in massive waste flows and material losses, into new economically, socially and environmentally sustainable circular economy models. To support manufacturers in this paradigm shift, a next generation of knowledge-intensive and high-efficiency de- and remanufacturing systems should be developed, enabling to deliver high quality upgradable and re-usable future products at affordable price to the global market.

De- and Remanufacturing systems include the set of technologies, tools and knowledge-based methods to recover, re-use, and upgrade functions and materials from post-consumer high-tech products. Short life cycle of products, high product variety as well as the high variability in the conditions of post-consumer parts and poor information about return products undermine the performance of traditional de-and remanufacturing systems. Efforts to develop efficient de-and remanufacturing systems should focus on multi-level approaches, addressing issues at product, process, system as well as the entire value-chain levels and should integrate best practices from emerging enabling technologies, under a systemic approach. These developments will support a sustainable transition towards the implementation of innovative manufacturer-centric circular economy businesses, in high value-added manufacturing sectors.

Specific technological (or non-technological) enablers or solutions that need to be addressed by the research or innovation activities.

- Develop new manufacturer-centric circular economy strategies, grounding on the availability of in-depth product knowledge for achieving improved recovery and re-use of product components and materials by de-and remanufacturing processes.
- Achieve radical increase in the range of products that are suitable for circular economy businesses through smart and adaptive de-and remanufacturing systems, integrating flexible disassembly and sorting, in-line inspection, multi-material joining, additive manufacturing and coating technologies for product or component repair and upgrade. This highly-adaptive systemic solution will enable to re-use complex, currently unrecovered, multi-material parts in a cost-effective way.
- Increase the quality of remanufactured products by developing radically new systemic zero defect de-and remanufacturing solutions for properly handling return product variability, both in terms of part variants and conditions. This goal should be achieved by a cross-technology approach grounding on the proper integration of distributed sensor networks for in-line inspection and data gathering, ICT digital models and optimization tools to support intelligent decision-making and system reconfiguration capabilities to adapt the processes to the specific quality characteristics of the incoming parts.
- Develop innovative human-centric solutions for de-and remanufacturing operations, including cooperative automation solutions and user-friendly knowledge management tools and decision support systems for complex product disassembly tasks.

- Develop innovative customer-oriented de-and remanufacturing production control methods able to deliver materials and components on-demand at the required quality and service levels. These methods should contribute to properly handle the uncertainty in the market and the variability of material values, thus enabling economic viability of de-and remanufacturing solution.
- Support a wide implementation of the developed de-and remanufacturing systemic solutions by new business models and value-chain organizations, strengthening cooperation mechanisms among the supply chain stakeholders, with substantial involvement of SMEs. The new operational models should guarantee, at the same time, availability of return products by effective reverse logistics as well as market acceptance of the remanufactured and upgraded products, also targeting emerging market requirements and frugal product opportunities.

Expected impact

A next generation of efficient de-and remanufacturing technologies and systems should be developed enabling to increase resource and materials efficiency in manufacturing and to increase the competitiveness of European technology providers in the global market. The proposed circular economy businesses should contribute to the creation of new knowledge-intensive jobs at European level. Specific impacts are expected in terms of economic and environmental performance measures:

- Production of new products that re-use at least 10% of resources and materials.
- Reduction of de-and remanufacturing costs of at least 20% with respect to currently adopted processes.
- Reduction of production costs, for products with re-usable components, of at least 30%.
- Decrease in waste and scraps in de-and remanufacturing of at least 40%.

2.4.2 Energy efficiency in Manufacturing (HL06)

The challenge/vision

Innovative production facilities must minimise energy use while generating less emissions and waste or re-using them exploiting industrial symbioses. Those goals require a systematic integration of environmental efficiency evaluation through the design/configuration and control/management phases, by a multi-level approach that covers production processes, machines, systems and, possibly, the supply chain. Effective environmental optimization and monitoring of the obtained improvements require the definition of robust key performance indicators (KPI), quantifying the energy efficiency level of production machinery and factories, independently from the kind of product being actually produced. Such methodologies will also support the ongoing European environmental regulatory activity.

Additionally, the growing proportion of renewable energy sources raises the volatility of the overall European Energy supply. Factories play a major role as flexible prosumers and can counteract this tendency, developing smart and adaptive solutions to quickly cope with a varying energy supply level. Factories interact with the urban surroundings in terms of energy exchange and integrated demand-side response. Pervasive industrial adoption of the developed solutions asks for automated and distributed Cyber Physical Systems (CPS) and ICT systems.

Specific technological (or non-technological) enablers or solutions that need to be addressed by the research or innovation activities.

- Green hybrid and cleaner processes. Net shape manufacturing of multi material components. Joining processes (for example laser welding, electron beam welding) with improved energy efficiency.
- Technologies to empower optimal heat management and industrial symbiosis. Methods and tools for optimal thermal design: efficient focused process heating (e.g. by induction, laser, IR lamps, …); high accuracy machines with minimized temperature control requirements; energy harvesting and waste heat reuse; electricity generation from Low Temperature heat (<100 C°)
- Environmental assessment and energy control and management of existing production facilities. Innovative sensors, digital platforms and CPS providing the required intelligent capabilities (i.e. sensing, processing, monitoring).
    - IT/ICT Technologies and models for energy monitoring and assessment. Automated model learning and updating exploiting continuous data collection from the field (e.g. wear and damage monitoring). Synchronization between real system and energy models by exploiting a CPS approach. Integration of environmental impact models in CAE/PLM software.
    - IT/ICT Technologies and models for energy control. ERMS (Energy and Resource Management System): smart and adaptive real time control strategies for manufacturing equipment, applied at system, factory, building and supply chain levels, with simultaneous optimization of energy, cost and quality.
    - Energy management and Integration of the factory within the grid. Management of on-site energy generation and recovery units (e.g. CHP, ORC, etc.) explicitly considering the integration of the factory within the grid, including production process constraints and objectives, energy prices fluctuation within the spot market, emissions minimization.

Expected impact

- -30% on energy use for a given production in industrial environment, applicable also by retrofitting to existing production plants
- allow operation of high precision machines in a normal industrial environment (18-25°C), eliminating the need for temperature controlled environments
- +50% in energy harvesting and/or heat re-use
- estimation of energy use & environmental impact for a new production batch and/or a new production plant within 10% error

2.4.3 European Circular Economy Open Platform (HL28)

The challenge/vision

There is a strong need to proactively drive Circular Economy innovation potential to EU Manufacturing Industry. Reducing resource and energy usage requires a cradle to cradle approach which recognizes that many processes are involved upstream and downstream of a supply chain. To achieve such reductions, it is needed to take into account all factors involved like recycling, heat recovery, efficient water use and lowering emissions to air, water and soil. The use of innovative technologies, methods and materials including recycling, de- and re-manufacturing will bring major reductions in material and energy consumption, essential for reducing the environmental footprints not only to process industry sectors but also to- vital sectors such as transport, construction, health and power generation as well as every citizen. This may include engaging raw material suppliers and final transformation industries in developing new innovative combined processes which result in the elimination of overlapped manufacturing stages. Circular Economy extends steep sustainability by introducing new technologies and services for de- and re-manufacturing.

A European Circular Economy Open Platform should be seen as an extension of a PLM platform by adding de- and re-manufacturing services. Research on completely new reference model and reference architecture to be developed and experimented on the field. The Platform should consider product-service combinations for new products design.

Enabling product servitisation allows to track the product and services along the whole lifecycle and consequently enhance customers' experiences and satisfaction through the melting of the physical and the cyber services aspects to a point where one won't exist without the other. Lifecycle management will moreover ensure the full exploitation of well-structured data and information, enabling high efficiency and added value in all the phases, from the design to the recycling.Still, services, mostly originated by new ICT such as IoT, Data Analytics, Deep Learning and Artificial Intelligence, are usually added on top of existing products, to extend them, but are not conceived together with the product, as a unique value proposition. Such situation can hamper the analysis of service usage and acceptance, reducing the possibility to make it more adherent to customer's expectations.

Specific technological (or non-technological) enablers or solutions that need to be addressed by the research or innovation activities.

In order to achieve the desired "melting" of physical-products (e.g. personal and fleet vehicles, machine tools and their components, pumps and compressors, home appliances and white goods, intelligent textiles and footwear) and cyber-services during their whole lifecycle, the following areas have to be addressed:

- Analysis of the two different ways of modeling and implementing IT systems:

  1. event-driven bottom-up always-on IoT systems aim at being responsive with respect to unforeseen events, and

2. service-oriented cloud systems implement collaboration and interoperability of heterogeneous systems through standard at-your-service functionalities.

- Customer-centric design and engineering of product-service systems
- Service-driven physical products through life renovation, continuous evolution of the cyber part of complex product-service systems
- Enhanced customer experience through high added value integrated cyber based services demonstrated on both traditional and innovative products
- Enhance customer-focused fact based design through field data availability, being fully compliant with privacy norms
- Closure of lifecycle information loops, guaranteeing context-driven access to information and knowledge to all relevant users, starting from the customer himself, to maintenance personnel, designers and remanufactures
- Enhanced environmental impact through planned and carefully managed products end of life.
- Product re-engineering and re-design at end of life
- Advanced models for de-manufacturing and re-manufacturing introducing the post-life or the evolutionary life transformation concept to the Circular Economy.

Expected impact

- Disseminate novel, innovative de-manufacturing and remanufacturing concepts for various sectors and materials into industry.
- 30% Optimized de- and re-manufacturing processes
- 20% Shorter time-to-market for Circular products
- Creation of Innovation ecosystems for Circular Economy stakeholders
- Demonstrate the feasibility of physical and cyber services systems lifecycle management for large scale customer centric solutions
- Demonstrate at least 15% lifecycle cost products decrease
- Demonstrate at least 10% reduction environmental lifecycle impact of products
- Demonstrate the availability of data to enhance end of life (remanufacturing/recycling) phase, with reduction of costs of at least 20%

2.5 Interoperable digital manufacturing platforms: connecting manufacturing services

The essentials

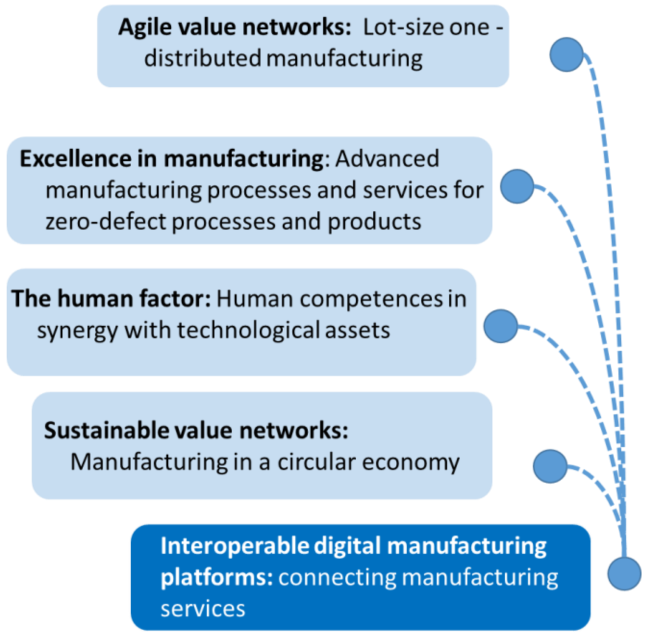
Digital manufacturing platforms are enabling the provision of services that support manufacturing in a broad sense. The services that are enabled by digital manufacturing platforms are associated to collecting, storing, processing and delivering data. These data are either describing the manufactured products or are related to the manufacturing processes and assets that make manufacturing happen (material, machine, enterprises, value networks and – not to forget – factory workers.

Services provided through digital manufacturing platforms can aim at:

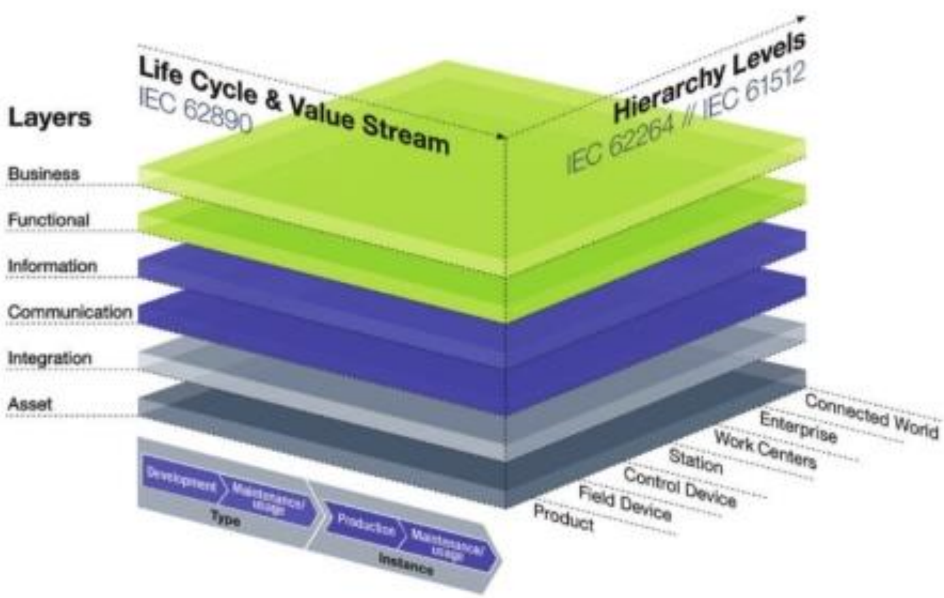
- Engineering of manufacturing
- Monitoring of manufacturing processes
- Data analytics through advanced automatic and human data science technics/technologies
- Manufacturing control involving an interaction among different agents, including machine-to-machine communication and the introduction of self-learning capabilities
- Simulation of manufacturing processes
- Assistance to factory workers and engineers, including augmented reality
- Planning of manufacturing, predictive and automated maintenance, etc.

These services are provided by multiple service providers for a multitude of users of these services (in a multi-sided eco-system).

All services are aimed at optimising manufacturing from different angles: production efficiency and uptime, quality, speed, flexibility, resource-efficiency, etc. Obviously, the key research priorities that are described in the previous sections are very much associated to these services. The key priority 'Interoperable digital manufacturing platforms: connecting manufacturing services' plays a pivotal role with respect to the deployment of many of the technologies and approaches under the 4 other key priorities:



The digital platforms are situated in-factory and ex-factory, i.e. the cloud. Pre-requisites for digital platforms to thrive in a manufacturing environment include the need for agreements on industrial communication interfaces and protocols, common data models and the semantic interoperability of data, and thus on a larger scale, platform inter-communication and inter-operability. As it is the case for any industry-relevant innovation, standards need to be considered, including work on reference frameworks or architecture models such as RAMI 4.0:



The Reference Architectural Model RAMI 4.0. © Plattform Industrie 4.0

Considering the fact that both within and outside the FoF PPP a lot of work on digital platforms has already been carried out, there is a need for activities that aim at validating the deployment of digital platforms for manufacturing with a focus on:

- The possibility to connect to additional services according to the 'plug-and-play' philosophy and considering the multi-sided ecosystem of service providers, platform providers and manufacturing companies
- Integrating legacy system (hardware and software)
- Overcoming semantic barriers
- Considering requirements of specific manufacturing sectors (process industry, consumer goods, capital equipment,…)
- Generating accessible technical and non-technical software documentation

Main recommendations for FoF 18-19-20

The FoF 18-19-20 work programme should focus on:

(In Word or pdf: Click for further details of the headline, Alt arrow to come back in the document)

- Digital Factory Modelling and Simulation
- Multiple Source (Big) Data Mining and Real Time Analysis at the Factory and Supply Chain/Network Levels
- CPS: Integration with physical legacy machines in factories
- Security, Privacy and Liability – Cybersecurity and Industrial Safety
- Digital Platform Interoperability

More references to FoF2020 vision (extracts from FoF 2020 roadmap)

FoF2020Quote-C 4: Competitiveness through optimal integration of different technologies: "Economic sustainability relies on an optimal implementation of the whole range of technologies and enablers, in particular involving ICT and robotics–mechatronics technologies, including embedded sensors connected to controllers, ERP, MES and predictive maintenance systems, enabling online, real–time and full production quality control. Europe requires leadership in the development, adaptation and commercialisation and speeding up of these innovation processes."

FoF2020Quote-C 6: Master complexity on supply chains level: "These challenges must be faced along the entire supply chain involving OEMs, component suppliers and SMEs due to the typical supply chains complex products"

FoF2020Quote-T 8: IoT: "Manufacturing processes should seamlessly and bi–directionally interact with real–world objects and environments on a global scale, across a variety of application domains and stakeholders, thus realising the 'Internet of things."

FoF2020Quote-C 11: Mastering data flows up to supply chains and reaching customers and workers: "High–performance production involves the management and processing of ever growing volumes of data and information from the factory floor up to the supply chain level, reaching out to workers and customers."

FoF2020Quote-T 10: Digital manufacturing platforms - 1: "Enterprise Information Systems (EIS) have to be opened up and made highly reliable to facilitate global collaboration across multiple organisations similar to the services offered on today's Internet. Globally accepted standards, methods, and tools have to be developed to enable large–scale infrastructures that can be configured, integrated, and monitored efficiently. Intelligent systems with advanced self–configuration, self–monitoring, and self–healing properties are required to manage the large and fast growing number of devices."

FoF2020Quote-T 11: Connectivity and security: "One of the biggest challenges for connectivity is that of security. Different stakeholders with varying business interests and hierarchy will access the product, production, and customer data outside enterprise boundaries to accomplish various manufacturing operations."

FoF2020Quote-T 12: Digital manufacturing platforms - 2: "ICT needs to focus on infrastructure mechanisms beyond pure connectivity that support manufacturing business needs (e.g. flexible manufacturing cloud services for storage and computation, robust and efficient security and payment mechanisms as well as means of dedicated information gathering and process analytics). Furthermore, the next generation of mobility–assisted manufacturing applications such as manufacturing and logistics traceability, product genealogy, cross–channel product distribution, and 'manufacturing app stores' should be developed"

FoF2020Quote-T 13: Big data and complex event processing - 1: "ICT research in manufacturing intelligence will assimilate the huge amount of data originating as a result of increased collaboration and connectivity and render meaningful information on–the–fly on mobile devices for managers and shop floor supervisors. Progress beyond the state of the art in complex event processing, real–time data analysis, and forecasting of complex scenarios originating in workplaces of the future needs to be made. Research, development and innovation (RD & I) in this area aims at providing full transparency across all stages of the manufacturing process. This transparency is required to optimise operational efficiency, and guarantee seamless tracking, tracing, and compliance."

FoF2020Quote-T 15: Big data and complex event processing -2: "A copious amount of data from the field and supply chain needs to be stored in a fault–tolerant way. New ICT solutions will allow complex queries on distributed and heterogeneous data sources to be run in fractions of a second. Business intelligence tools for complex data stream analysis facilitate real–time decision–making across all tiers of the enterprise."

FoF2020Quote-T 17: Digital manufacturing platforms - 4: "Distributed and collaborative applications will be implemented through 'mash–ups' of services implemented by different small and large ICT and manufacturing vendors. The cloud will be the meeting place for provisioning customised functionalities through services that are reliable, secure, and guarantee performance. Open standards will ensure the full inter–operability in terms of data and applications."

FoF2020Quote-T 18: Digital manufacturing platforms - 5: "Collaborative and decentralised application architectures and development tools: In extended enterprises and globalised markets, applications (e.g. life cycle management, supply chain management, monitoring and control, and customer relationship management) will no longer operate in closed monolithic structures. Stakeholders and customers collaborating on a common application platform implemented with the cloud approach will bank on new software development and testing environments more oriented towards non–technical users and support development of business processes. Distributed applications with low footprints targeting a large user base would be supported by enhanced business process re–engineering tools for rapid development and deployment.”

2.5.1 Digital Factory Modelling and Simulation (HL16)

The challenge/vision

The systematic exploitation of the Digital Factory models is a cornerstone in increasing manufacturing performance, and the ground is mature enough to further rely on ICT advancements as a lever to increase productivity and competitiveness (e.g. Industrie4.0; Fabbrica Intelligente; Smart Industry…). The development of accessible digital factory models and proper simulation tools will empower effective industrial decision making, optimizing factory development time, efficiency and output quality also for SMEs. During the lifecycle of a factory, huge amounts of data are generated by various tools, whose accessibility and interoperability is hampered by proprietary closed solutions. Legacy tools are often originating from domain specific, non-reusable, inaccessible engines. As opposed to large, closed and monolithic factory-simulation frameworks, an open European ecosystem accessible to SMEs seems more appropriate for unleashing the innovation potential of both providers and users.

The aim of research and innovation activities is to pave the way to a holistic virtual production approach to factory development and evolution. Simulation and modelling methods and tools are needed, within SMEs and SMEs' networks, to support the whole lifecycle of production systems and supply chains, which are capable to sustain constant real-time data acquisition from all the factory resources. For instance, discrete event simulation or other simulation tools predict future events and also they can be combined with data mining based statistical analysis (trends, pattern, relationships, correlations, and logistic regression and other forecasting methods), to optimize the next steps. The visual and interactive tools can be used to support analytical reasoning and for finding insight from data. Those modelling approaches and simulation applications need to support access and usability at different levels, from operators to managers, with different objectives (evaluation of total cost and value of industrial assets, economic performance, logistics, operations, energy consumption, etc.) to support the decision-making processes, activity planning and operation controlling. Interaction with legacy product lifecycle management, manufacturing execution and enterprise resource planning systems is to be addressed.

Specific technological (or non-technological) enablers or solutions that need to be addressed by the research or innovation activities.

The challenges to pursue a comprehensive Digital Representation of Factories are several.

- The first is to tackle the whole lifecycle of the production system, integrating diverse models from different domains and disciplines, since the early conceptual design phase. The information developed within this early phase is to be upheld all along the entire factory life-cycle, despite changes in purpose and tools, allowing data to be enriched, updated, and used as needed in each specific phase (e.g. through the development/consolidation of proper standards).
- The second aspect is to address (through proper simulation apps) integrated scalable factory models and tools for multi-level access features, aggregation of data with different granularity, zoom in and out functionalities.
- The third challenge is the harmonization of Digital and Real World, where the digital factory corresponds to an exact real-time copy of the production environment (e.g. thanks to CPS based

factories), so to enable factories to run production tests in quasi real-time or to create accurate digital prototypes of products. Operative manufacturing planning needs always up to date data from heterogeneous sources, automatic model building and re-building on request and in short time frame.

- The fourth aspect is related to the development of advanced tools for supporting decision making in manufacturing operations (surfacing, joining, cutting, additive manufacturing, machining etc., still provided with an app-like approach)

Expected impact

- Achievement of common semantic understanding. Definition of open interfaces, data formats and protocols.
- Improved accessibility (cost and scope) of simulation services by SMEs.
- Reduced time to production and optimization, enabled also by increased interoperability and data integration. Increased efficiency within design and ramp-up phases. 20% faster time to production.
- Improved accuracy and reliability of simulations in manufacturing processes
- Time to manufacturing system optimization (through simulation) down of 20%.
- Improve life cycle costs performances within specific industrial application, by providing empirical evidence of application of CPS-based simulation solution

2.5.2 Multiple Source (Big) Data Mining and Real Time Advanced Analytics at the Factory and Value Network Levels (HL17)

The challenge/vision

Data collection and real time analytics for novel supply chain/network approaches for innovative products enable collaborative demand and supply planning, traceability, and execution, and help engineers to design new products and production equipment, as well as new product service systems, permitting the propagation of the servitisation and the redesign business models for Ecosystems of Product-Service.

One of the main challenges lies in the fact that data needs to be collected from a context of heterogeneous and knowledge sources from both distributed production and business processes with the complexity of time zones and geographical spread spaces. The next challenge is to analyse this data and control processes, e.g. machine automation, quality control, and condition management, and to use this data for business intelligence decisions.

A new scale of magnitude of complexity arises from this landscape to ensure that data are available, protected and reserved. Here the pragmatic balance needs to be found between data openness and privacy requirements.

Specific technological (or non-technological) enablers or solutions that need to be addressed by the research or innovation activities.

- Improved methods of gathering valuable machine data and data integration/harmonisation across different sources
- Implementation of advanced data analytics technologies and methods, including artificial intelligence, aiming for instance at the development of
    - algorithms that adapt reliably according to the intended changes of raw materials, normal wearing of machinery, changes of operative states, etc.
    - algorithms that are capable of predicting all kinds of behaviour that would enable true condition based or predictive maintenance, forecast the product qualities performance indicators
    - algorithms that correlate product, process and business related information
- Demonstrate the use of manufacturing and product data for various objectives and different factory levels: machine, shop floor, control and management levels and the supply chain/network
- Tools for forecasting, monitoring and visualising benefits and risks
- Data architectures matching industrial needs, provision of the right information, to the right person at the right time
- Demonstration that the complexity of the viewable context is not depleting the quality of the available information to support decision making

Expected impact

- Demonstrate real time analytics along the whole Lifecycle and value chain, quantify benefits to the industrial sector, demonstrate how to make profit out of data

- Demonstrate capabilities regarding data visualisation and user interaction in this heterogeneous context
- Solving transmission data bottlenecks in the industrial sector
- Tools to quantify benefits in the implementation of (big) data mining and Real-Time Advanced Analytics

2.5.3 CPS: Integration with physical legacy machines in factories (HL18)

The challenge/vision

Smart technologies and connectivity will improve flexibility and allow continuous control in industry that helps manufacturing firms to gain competetiveness.

The implementation of Cyber-Physical Systems imply wide application of IoT and smart embedded devices in manufacturing. The current trend is that new machines will natively embed IoT capabilities. Legacy machines need to be equipped with ad-hoc hardware to "cyber-ise" them. These will offer easier connectivity and machine integration, even in data intensive scenarios where heterogeneous sources will be managed and recorded.

There following aspects need to be taken into account:

- the "digital" version of the production system/module has to be filled with content (e.g. behavioral models, simulation capabilities, predictive conditions)
- Easy to use apps are needed for the digital factory to enable factory personnel to be included in the cyber-physical information loop provided with ad hoc and contextual content
- Advanced digital manufacturing should have human-like decision making capabilities
- Information for the production process control should be created or used independently by the different productive resources
- Available, usable, sharable information presented in the form requested by the various plant hierarchical levels

Specific technological (or non-technological) enablers or solutions that need to be addressed by the research or innovation activities.

In order to achieve a consistent approach to the industrial challenges of the future cyber-physical factories, the following areas have to be addressed:

- M2M communication for data exchange of system behaviours
- IoT Connectivity as an important key enabler
- Innovative industry floor IT Structures for automated control and supervision fed with sensor data
- Proactive Manufacturing through Smart Interaction in Event and Process Driven Architectures
- "Cyber-isation" of legacy machines and integration of new IoT compliant machines with legacy production lines
- Inclusion of total cost of ownership and environmental/energy efficiency aspects into the factory optimization

Expected impact

Projects should demonstrate that the project will have a positive impact on one or more of the following criteria:

- Saving in the integration of IoT compliant machine within an existing line;

- Convincing demonstration of cyber-isation of legacy machines/lines;
- Deployment of factory apps with a shorter ROI
- High usability and smooth learning curve;
- Demonstration of new connected or IoT compliant systems
- Better production system lifecycle management, thanks to the accurate control of the CPS elements of the system.
- Proven delegation of management and order execution to machines in a network
- Better utilisation of machines, enabled by the distributed and real-time control
- Reduced barriers for migration to plug-and-produce

2.5.4 Security, Privacy and Liability – Cybersecurity and Industrial Safety (HL26)

The challenge/vision

Implementation of Data Security and Privacy solutions as CPS is dealing with big amount of data. Some of them are related to products, some to process, some to people (worker and customer). A complete new scale of magnitude of complexity arises from this landscape to ensure that data are available, protected and preserved.

From a technological point of view the adoption of IoT-related technologies increase the challenge of data security and protection, since (critical) data and software are no longer centralized in (relatively) controlled computing environments but spread to the edge of the cloud and back. The complete loop in the IoT sense (sense-plan-act) also engenders safety problems, since factory floor actuators (robots, machines) can then be steered by remotely computed decisions, or in a distributed manner by complex algorithms.

Organizational issues in the manufacturing domain are related to long and complex supply-chains. Each company and industry varies in the type of information it considers as most important: For manufacturers the data that is of most value includes intellectual property on patents, designs and formulas. It is of utmost importance then to design security programs to protect business-value data, at each level of the factory, from the office floor to the shop floor and all along the supply chain. From encryption to digital rights management and persistent document tagging, to policy-driven data protection, there are numerous approaches to ensure data flows freely, but only on a need-to-know basis.There is a need for:

- new Information Security approaches and related standards
- Identify the Security Service Level Agreements (SLAs) for manufacturing
- Identify the Safety SLAs for manufacturing
- Develop security and privacy frameworks in the new digitized context
- Accountability and trust management
- Models on how data can and will be used in and ex-factory
- Models on data exchange and trade among 3rd party suppliers
- Business models for continuous Cybersecurity improvement

Specific technological (or non-technological) enablers or solutions that need to be addressed by the research or innovation activities.

- Addressing Cyber-security, Privacy, data protection and trusted third parties
- Distributed and concurrent control systems: from design to verification
- Develop models for data ownership, and the shared value of the information (ownership of value data)
- Computation on encrypted data
- Software security analyses of critical data-management components
- Research on Security and Safety Management in an Industry 4.0 context
- Metadata structure for new data frameworks and exchange platforms
- Data architecture for the data marketplace

- Efficient monitoring of security policies in digital systems
- Lightweight security for communication protocols in low power resources
- Formal models and tools for data security
- Research on new manufacturing related industrial process control and safety systems
- Validation of machine learning algorithms and distributed decision algorithms
- Trusted components for manufacturing control systems
- Research on new Manufacturing Security Governance
- Research on Machine Ethics

Expected impact

- Respect for and protection of the individual and the group and the location
- Implementation of Data Security and Privacy solutions related to data of/from products, processes, workers and customers
- Implementation and Legislative-ready Manufacturing Data frameworks and Data Sharing Compliance frameworks
- Definition of Personal Information Architectures and Access Control Policies
- Digital systems assessment guidelines and evaluation
- Shaping a data governance model and rules for data exchange, taking into account the legal framework and the business interests of companies

2.5.5 Digital Platform Interoperability (HL25)

The challenge/vision

The diversity of approaches and implementations of digital manufacturing platforms, implies the need for the creation of Meta-Platforms to connect existing platforms, including abstraction layers for interface, protocol and data mapping to provide interoperability as a service. There is a need for holistic interoperability solutions spanning all communication channels and interfaces (M2M, HMI, machine to service) in the factories and supply chains.

(Note: In cooperation with many projects that work on digital platforms, the ConnectedFactories CSA will contribute to the mapping of technologies and approaches, relevant standards and protocols for domain specific open platforms and reference architectures)

Specific technological (or non-technological) enablers or solutions that need to be addressed by the research or innovation activities.

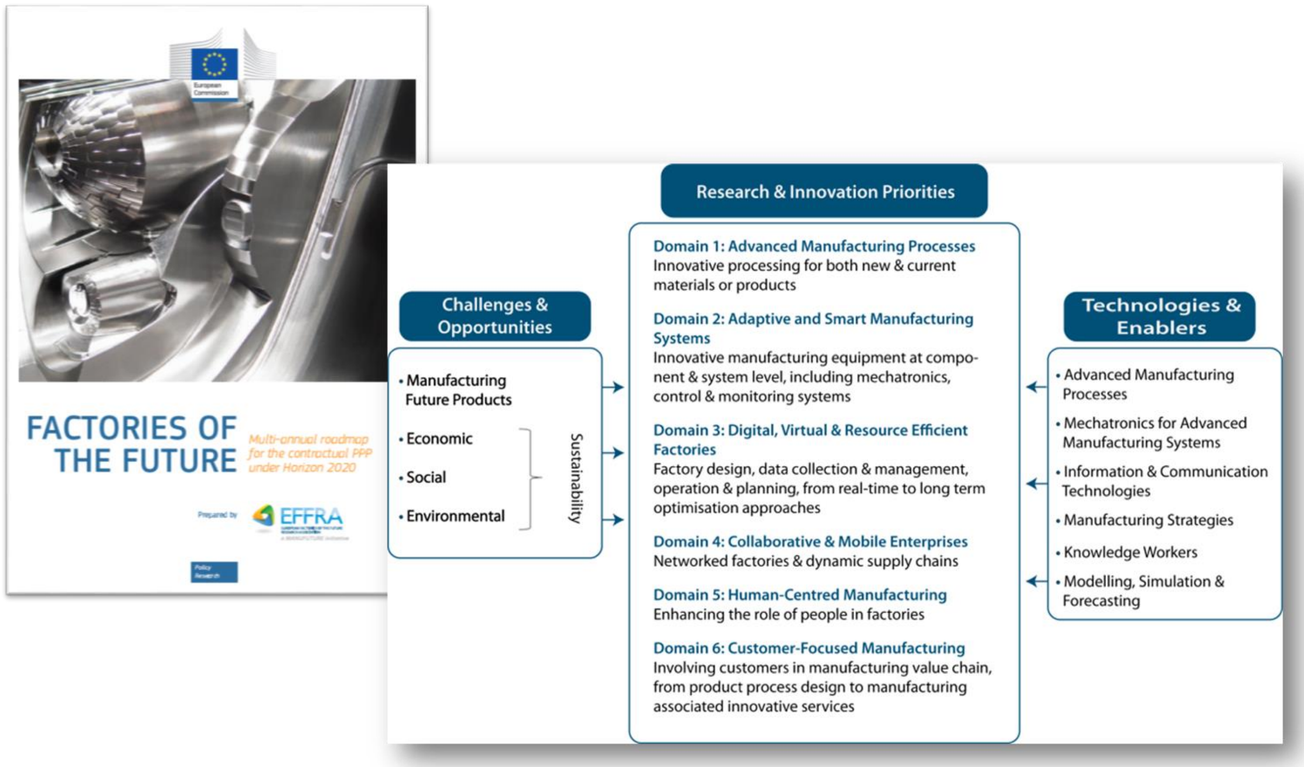
- Combination or incorporation of existing national and international standards into European standards
- Empowering of platform inter-connectivity by common API definition and usage
- Development of semantic models based off domain specific standards
- Introduction of semantic meta models to exchange information across domains
- Creation of integration layers which provide extended interoperability between systems and platforms
- Consideration of all industrial communication technologies leading to the cloud
- Use of appropriate cloud architecture, including for ex. FOG/EDGE structures
- Application and clustering of established and emerging standards and identification of gaps in relevant and established standards

Expected impact

- Reduction of complexity and cost, increase of efficiency in technological integration and adaptation
- Increase in security, safety and resilience due to common technological understanding
- Enabling of paradigm shifts in regard to company collaboration and business models from products, to services over to solutions
- Clustering of common standards and creation of condensed standards
- Advanced mapping and definitions of Reference Architecture Layers, Hierarchy, and Value Stream & Lifecycle
- Advanced digital manufacturing platform requirements specifications
- Advanced digital manufacturing platform product and process documentations

3 References: the vision of Factories of the Future 2020

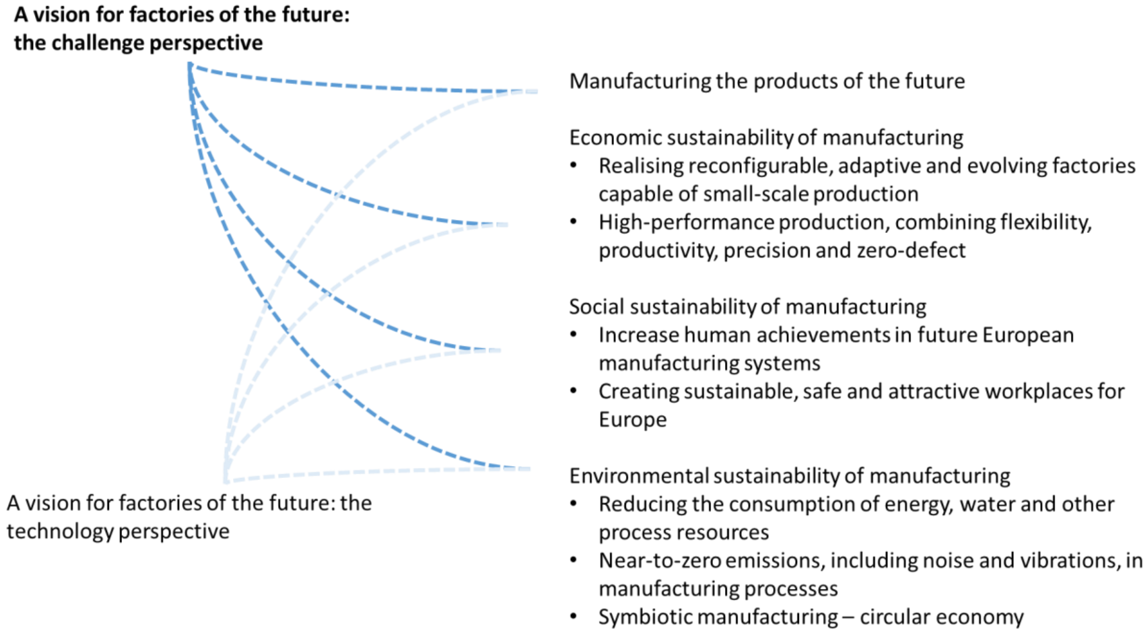
This document is building on the Factories of the Future 2020 roadmap that is the basis of the contractual arrangement for the Factories of the Future PPP.



The FoF 2020 roadmap (published at the end of 2013) describes the vision of the Factories of the Future both from the perspective of challenges (or ultimate targets) and from the perspective of enabling technologies. In the description of the five key priorities described in the previous chapter, reference to these visionary statements of the FoF 2020 roadmap – that appear to be still very actual – have been included.

In the following paragraphs, these visionary statements from the FoF 2020 roadmap are bundled again according to the challenge and technology perspectives (this is the structure in which they appear in the FoF 2020 roadmap.

3.1 A vision for factories of the future: the challenge perspective



3.1.1 Manufacturing the products of the future

3.1.1.1 FoF2020Quote-C 1: Personalised products
"Global competition requires the launch of new products with a shortened commercial life cycle and with a high degree of personalisation for adapting to individuals biometric parameters or for satisfying unique users' preferences. On the other side, sustainability is pushing for an extension of the life cycle itself. This dilemma can be solved by highly personalised products through software functionalities, which can easily sustain high frequency of renewal, or by the design of products, processes and systems that allow the sustainable re-manufacturing and materials recycling. "

3.1.1.2 FoF2020Quote-C 2: Increased product intelligence
"Service provisioning and enhanced functionalities in future products will also require the introduction of increased product intelligence, such as the increased use of embedded mechatronics in components, which will require the design and production methodologies to evolve as a consequence."

3.1.2 Economic sustainability

3.1.2.1 FoF2020Quote-C 3: High-value added manufacturing through smart production
"Economic sustainability through high value-added manufacturing using production processes with a high degree of intelligence should be a distinctive factor for European industry."

3.1.2.2 FoF2020Quote-C 4: Competitiveness through optimal integration of different technologies
"Economic sustainability relies on an optimal implementation of the whole range of technologies and enablers, in particular involving ICT and robotics-mechatronics technologies, including embedded sensors

connected to controllers, ERP, MES and predictive maintenance systems, enabling online, real-time and full production quality control. Europe requires leadership in the development, adaptation and commercialisation and speeding up of these innovation processes."

3.1.2.3 FoF2020Quote-C 5: Multi -material and multi -functional products

"Over the next decade, for a wide range of complex products, the holistic optimisation of performance will push towards new multi-material and multi-functional solutions. This will result in a change in the manufacturing paradigm by introducing new methods and process technologies within the factory in order to ensure both the required quality and sufficiently high productivity to guarantee cost-efficient manufacturing."

3.1.2.4 FoF2020Quote-C 6: Master complexity on supply chains level

"These challenges must be faced along the entire supply chain involving OEMs, component suppliers and SMEs due to the typical supply chain of a complex product."

3.1.2.5 FoF2020Quote-C 7: Flexible, evolvable and responsive factories

"Upgradable, evolvable machine, cell and plants are necessary for flexible and responsive manufacturing. New organisational approaches and tools are required for manufacturing a mix of different products within the same cell/line/plant, optimising the internal and external logistics (including the supply chain) which often becomes the real obstacle when very flexible production capability is available."

3.1.2.6 FoF2020Quote-C 8: Flexible manufacturing processes

"Highly flexible manufacturing processes, tools and systems will enable the manufacturing of smaller and more personalised batches. Novel industrial processes with an increased level of customisation, tailored for individual needs, involving the user/customer in the loop at the early step of design."

3.1.2.7 FoF2020Quote-C 9: High performance and zero-defect manufacturing

"High-performance production requires an increase in terms of speed, quality and reliability of existing manufacturing technologies. It requires process monitoring and modelling or simulation approaches, associated with novel optimisation and maintenance strategies. "

3.1.2.8 FoF2020Quote-C 10: Highly integrated and smart manufacturing processes

"Innovative manufacturing technologies should also be developed; increasing the value-creation of one single operation. High-performance production will be furthermore largely supported by introducing advanced mechatronics and embedding intelligence in manufacturing equipment."

3.1.2.9 FoF2020Quote-C 11: Mastering data flows up to supply chains and reaching customers and workers

"High-performance production also involves the management and processing of ever growing volumes of data and information from the factory floor up to the supply chain level, reaching out to workers and customers."

3.1.3 Social sustainability

3.1.3.1 FoF2020Quote-C 12: Integrating human and machine intelligence through ICT - 1

"Human capability and machine intelligence will be integrated within production systems that can achieve maximum efficiency as well as worker satisfaction. Research efforts should tackle social sustainability challenges at all levels of manufacturing industries. This effort will be economically very successful, while still improving corporate social responsibility, inclusive workplace design, and efficient use of ICT to leverage the competence of the European workforce."

3.1.3.2 FoF2020Quote-C 13: Integrating human and machine intelligence through ICT - 2

"Future knowledge-workers should interact dynamically and share tasks with smart manufacturing technology. Collaboration and allocation of tasks between humans and manufacturing technology should be done through appropriate and adjustable levels of physical and cognitive automation. Human capabilities should be enhanced e.g. by safe human–robot collaboration, mobile and location-aware communication devices, and customer–worker collaboration capability. Within this context, manufacturing education has a key role in preparing humans for new approaches to knowledge communication, skill and competence development, and advanced training. "

3.1.3.3 FoF2020Quote-C 14: Tools for supporting the role of workers -1

"Interdisciplinary research and innovation activities will provide value systems that inspire humans to achieve results not thought to be possible today. Future enabling methods include virtual and analytical task analyses, dynamic risk and safety assessment, cognitive workload analyses, and competence management tools."

3.1.3.4 FoF2020Quote-C 15: The ICT Generation

"The next generation workforce is being raised in an Internet society and is accustomed to a vast range of technical gadgets and rich interaction techniques."

3.1.3.5 FoF2020Quote-C 16: Tools for supporting the role of workers - 2

"Future enabling methods will push the boundaries of simulated work environments, augmented reality, and virtual human models in order to visualise and analyse the behaviour of broad ranges of workers."

3.1.3.6 FoF2020Quote-C 17: The social aspects of local manufacturing

"In the near future, enterprises will have to seek production sites in places of high population density. Accelerated population aggregation in urban regions will affect citizens living close to manufacturing plants. Consideration of social responsibility to local environments is increasingly important and needs scientific answers as to how to make manufacturing plant location economically profitable with respect to energy demands, quality of living, natural resources, and safety. "

3.1.3.7 FoF2020Quote-C 18: Tools for supporting the role of workers -3

“Future enabling methods will include new organisational models, new value systems, and new global business models. Sustainable care and responsibility is closely linked to environmental and economic sustainability. This will attract highly motivated and skilled employees."

3.1.4 Environmental sustainability

3.1.4.1 FoF2020Quote-C 19: Sustainability across the supply chain

"This requires the exploitation of innovative energy-efficient actuators and components to their full extent while also considering the entire supply chain, from raw material manufacturing stages up to the final component manufacturing process."

3.1.4.2 FoF2020Quote-C 20: Monitoring for sustainability

"Process monitoring and control can provide support here, for optimising the performance and resource consumption on machine level and factory and supply chain level, where decision- support systems consider energy consumption globally. This includes selectively switching off systems and components, using smart sensor networks and energy-efficient scheduling approaches, reducing peaks in energy demand, recovering and reusing electrical energy from decelerating drives or process heat, etc. Process monitoring should also support the consideration of resource-efficiency in maintenance approaches."

3.1.4.3 FoF2020Quote-C 21: Simulation and modelling for sustainability

"Simulation and modelling methods and tools that consider resource consumption and emissions will have an impact both in the design and operational phase of manufacturing systems. Here, it is important to use life cycle analysis in order to avoid sub-optimisation and to promote transparency."

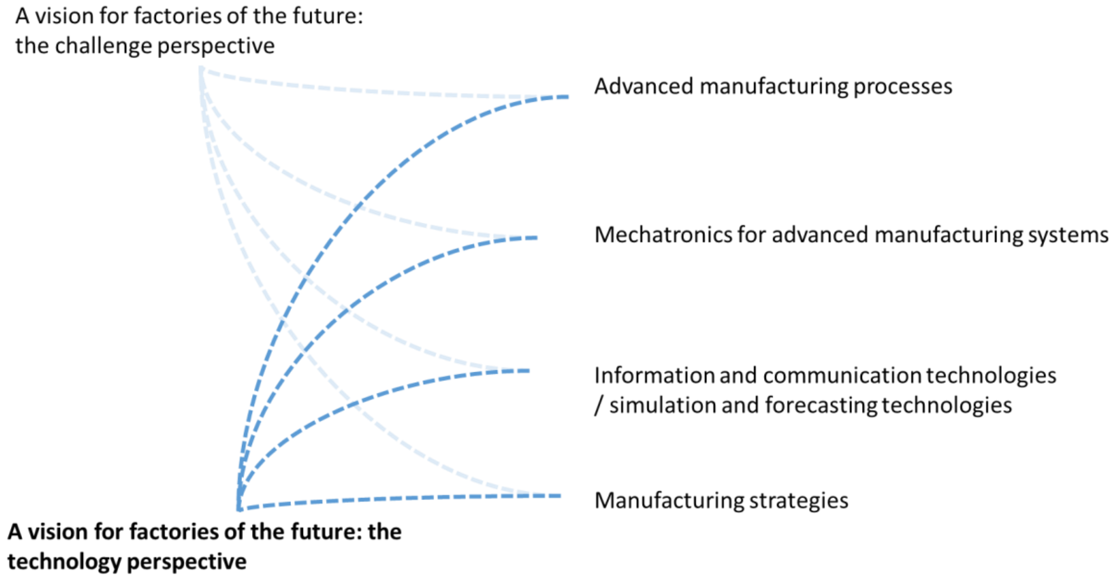
3.1.4.4 FoF2020Quote-C 22: Near-net for material efficiency

"Optimal use of materials also involves increasing the deployment of near-net manufacturing processes, such as additive manufacturing, hereby reducing raw material consumption and allowing production of highly customised level design."

3.1.4.5 FoF2020Quote-C 23: Synergy on process and supply chain level

"Co-evolution of products–processes–production systems involves engaging traditionally separate industries involving physical exchanges of materials, energy, water, and/or by-products 40 and requires an optimised interaction of manufacturing with transport and critical infrastructures."

3.2 A vision for factories of the future: the technology perspective



3.2.1 Advanced manufacturing processes.

3.2.1.1 FoF2020Quote-T 1: Advanced material processing

"Innovative products and advanced materials (including nano-materials) are emerging but are not yet developing to their full advantage since robust manufacturing methods to deliver these products and materials are not developed for large scale. Research is needed to ensure that novel manufacturing processes can efficiently exploit the potential of novel products for a wide range of applications. "

3.2.2 Mechatronics for advanced manufacturing systems

3.2.2.1 FoF2020Quote-T 2: Adaptive and connected smart systems

"Learning controllers adapt the behaviour of systems to changing environments or system degradation, taking into account constraints and considering alternatives, hereby relying on robust industrial real-time communication technologies, system modelling approaches and distributed intelligence architectures."

3.2.2.2 FoF2020Quote-T 3: Cognitive systems

"Cognition-based intelligent features within machinery and robots will radically change their interfacing towards human operators in manufacturing environments. Machinery and robots will follow an intuitive cooperation and will use navigation and perception technologies to be aware of its work and of its environment. "

3.2.2.3 FoF2020Quote-T 4: Ubiquitous connectivity - 1

"Advanced machine interaction with humans through ubiquity of mobile devices and novel natural interaction devices will enable users to receive relevant production and enterprise-specific information regardless of their geographical location and tailored to the context and the skills/responsibilities they own. Interactions with ICT infrastructures and equipment will be intuitive and natural language-like."

3.2.3 Information and communication technologies

3.2.3.1 FoF2020Quote-T 5: Ubiquitous connectivity - 2

"Manufacturing is evolving from being perceived as a production-centred operation to a human-centred business with a greater emphasis on workers, suppliers and customers being in the loop"

3.2.3.2 FoF2020Quote-T 6: Increased services through connectivity

"OEMs will be able to offer value-added services (e.g. maintenance, upgrade) or even sell their 'products as a service'. Remote service management helps to improve equipment uptime, reduce costs for servicing (e.g. travel costs), increase service efficiency (e.g. first-visit-fix-rates) and accelerate innovation processes (e.g. remote update of device software). Through customer collaboration future ICT solutions would enable extraction of customer and after-sales information from sources such as the social networks and feed this information to develop personalised and customised end-products of the future."

3.2.3.3 FoF2020Quote-T 7: Ubiquitous connectivity - 2

"Connectivity is inherent to the development of the future workplace."

3.2.3.4 FoF2020Quote-T 8: IoT

"Manufacturing processes should seamlessly and bi-directionally interact with real-world objects and environments on a global scale, across a variety of application domains and stakeholders, thus realising the *'Internet of things'."*

3.2.3.5 FoF2020Quote-T 9: Tools for supporting the role of workers -1

"Workers' direct interaction with physical systems will enable processes that are real-world aware, event-based, and significantly more adaptive than today's processes, which will result in increased visibility, responsiveness, and safety in the workplace of the future."

3.2.3.6 FoF2020Quote-T 10: Digital manufacturing platforms - 1

"Enterprise Information Systems (EIS) have to be opened up and made highly reliable to facilitate global collaboration across multiple organisations similar to the services offered on today's Internet. Globally accepted standards, methods, and tools have to be developed to enable large-scale infrastructures that can be configured, integrated, and monitored efficiently. Intelligent systems with advanced self-configuration, self-monitoring, and self-healing properties are required to manage the large and fast growing number of devices."

3.2.3.7 FoF2020Quote-T 11: Connectivity and security

"One of the biggest challenges for connectivity is that of security. Different stakeholders with varying business interests and hierarchy will access the product, production, and customer data outside enterprise boundaries to accomplish various manufacturing operations."

3.2.3.8 FoF2020Quote-T 12: Digital manufacturing platforms - 2

"ICT needs to focus on infrastructure mechanisms beyond pure connectivity that support manufacturing business needs (e.g. flexible manufacturing cloud services for storage and computation, robust and efficient security and payment mechanisms as well as means of dedicated information gathering and process analytics). Furthermore, the next generation of mobility-assisted manufacturing applications such as manufacturing and logistics traceability, product genealogy, cross-channel product distribution, and 'manufacturing app stores' should be developed."

3.2.3.9 FoF2020Quote-T 13: Big data and complex event processing - 1

"ICT research in manufacturing intelligence will assimilate the huge amount of data originating as a result of increased collaboration and connectivity and render meaningful information on-the-fly on mobile devices for managers and shop floor supervisors. Progress beyond the state of the art in complex event processing, real-time data analysis, and forecasting of complex scenarios originating in workplaces of the future needs to be made. Research, development and innovation (RD & I) in this area aims at providing full transparency across all stages of the manufacturing process. This transparency is required to optimise operational efficiency, and guarantee seamless tracking, tracing, and compliance."

3.2.3.10 FoF2020Quote-T 14: Digital manufacturing platforms – 3

"ICT solutions for factory floor and physical world inclusion: Real-world resources such as machinery, robots, lines, items and operators (..) need to be connected to each other and to back-end systems and at the same time to be self-aware of the surrounding environment."

3.2.3.11 FoF2020Quote-T 15: Big data and complex event processing -2

"ICT solutions for next generation data storage and information mining: A copious amount of data from the field and supply chain needs to be stored in a fault-tolerant way. (…) New ICT solutions will allow complex queries on distributed and heterogeneous data sources to be run in fractions of a second. Business intelligence tools for complex data stream analysis facilitate real-time decision-making across all tiers of the enterprise."

3.2.3.12 FoF2020Quote-T 16: Digital manufacturing platforms and modelling and simulation

"ICT solutions for modelling and simulation tools: Complex environments need to be consistently described by semantic models in order to correlate information, describe the dynamics, and forecast their behaviour. Knowledge from different sources (e.g. human, experience, research) will be made available and fully exploited by dedicated modelling and simulation tools. Here the main priorities are concern-integrated simulation techniques (product–process– production systems)."

3.2.3.13 FoF2020Quote-T 17: Digital manufacturing platforms - 4

"ICT solutions for implementing secure, high-performance and open services platforms: Distributed and collaborative applications will be implemented through 'mash-ups' of services implemented by different small and large ICT and manufacturing vendors. The cloud will be the meeting place for provisioning customised functionalities through services that are reliable, secure, and guarantee performance. Open standards will ensure the full inter-operability in terms of data and applications."

3.2.3.14 FoF2020Quote-T 18: Digital manufacturing platforms - 5

"Collaborative and decentralised application architectures and development tools: In extended enterprises and globalised markets, applications (e.g. life cycle management, supply chain management, monitoring and control, and customer relationship management) will no longer operate in closed monolithic structures. Stakeholders and customers collaborating on a common application platform implemented with the cloud approach will bank on new software development and testing environments more oriented towards non-technical users and support development of business processes. Distributed applications with low footprints targeting a large user base would be supported by enhanced business process re-engineering tools for rapid development and deployment. "

3.2.4 Manufacturing strategies

3.2.4.1 FoF2020Quote-T 19: Manufacturing strategies

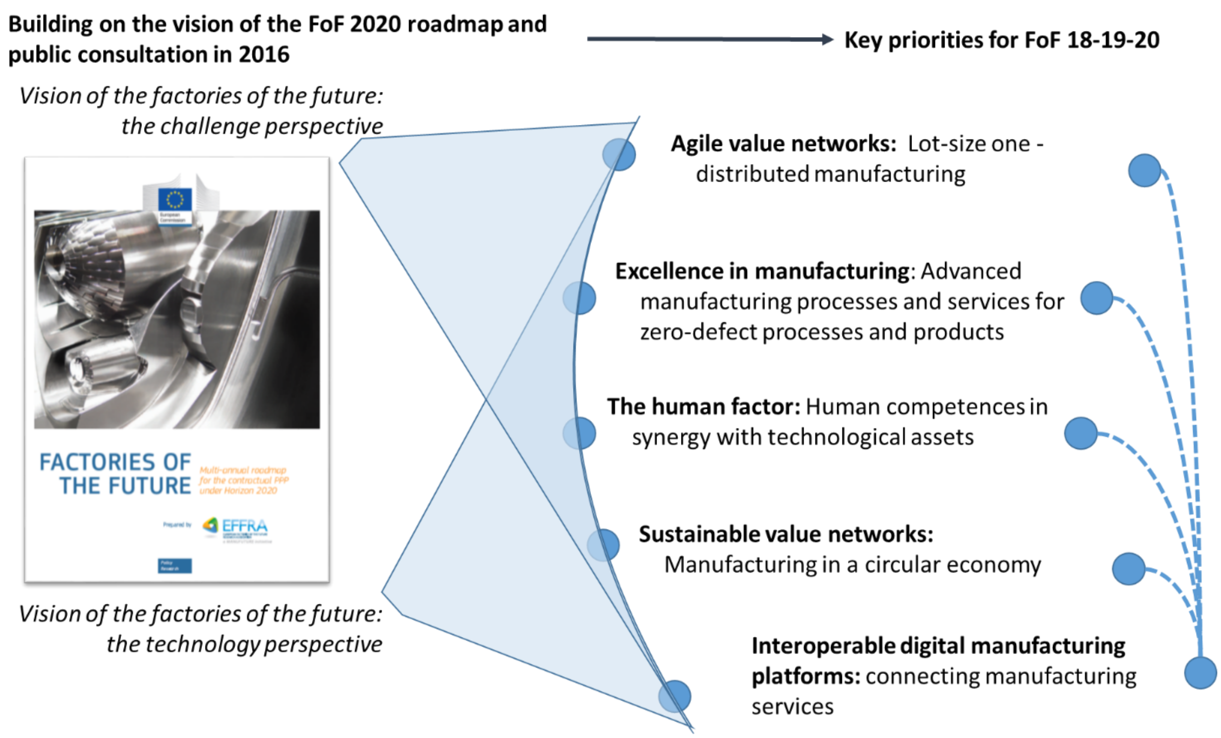
"Research and innovation for the Factories of the Future is not only a matter of developing and integrating novel technologies. Manufacturing challenges can only be properly addressed if the manufacturing community understands the mechanisms to create value. 'Thinking outside of the box' is not only required for generating technological innovation, it is also required for generating new approaches to operating supply chains and addressing markets."

4 Conclusions

This working document describes potential research headlines for the FoF 18-19-20 Work Programme, structured according to five key priorities:

- **Agile value networks**: Lot-size one – distributed manufacturing
- **Excellence in manufacturing**: Advanced manufacturing processes and services for zero-defect and innovative processes and products
- **The human factor:** Developing Human competences in synergy with technological progress
- **Sustainable value networks**: Manufacturing driving the circular economy
  and
- **Interoperable digital manufacturing platforms:** supporting an eco-system of manufacturing services

These key priorities are heavily building on the vision laid out in the FoF2020 roadmap.



These key priorities have been described through more detailed research headlines.

The goal of this document is to support the discussion about the future focus areas of the FoF PPP and the associated instruments (research and innovation actions, innovation actions, …)