INITIATIVE FOR EXCELLENCE IN DIGITAL INDUSTRY

CSA-Industry4.E

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Deliverable 1.1 Report on programmes and project's complementarities and synergies

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Summary

This deliverable presents the results of the analysis of roadmaps, programmes and projects related to the Industry4.E Lighthouse.

The **Industry4.E Lighthouse** has a special focus on all means of microelectronics and Information and Communications Technology (ICT) for Digital Industry. Operating across project, funding, and national boundaries, Industry4.E is expected to bring together relevant Research, Development and Innovation (RDI) projects funded across various programmes, helping projects to connect with each other and the end-user/stakeholder community.

Team involved in deliverable writing: MGEP, S2i, VTT

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1 Introduction

This deliverable (D1.1: Report on programmes and project's complementarities and synergies) presents the mapping and analysis of relevant roadmaps and ECSEL projects of the Industry 4.E Lighthouse.

D1.1 is part of the "Task 1.1 Identify overlaps, complementarity and added value regarding relevant roadmaps, programmes, activities and projects" that has been performed in two iterations. During the first iteration the main focus was the analysis of relevant roadmaps in order to identify emerging themes; a lighter but faster initial mapping and analysis of the ECSEL-JU projects of the Industry 4.E lighthouse was performed also. The first iteration's goal was to have first results as soon as possible and be able to deliver recommendations to the Industry4.E LIASE in time for the 2020 version of the Electronic Components & Systems Strategic Research Agenda (ECS SRA[1]). The initial work in iteration 1 has now been complemented and extended in this second iteration.

The deliverable presents the results of the analysis of relevant roadmaps and the analysis of ECSEL-JU projects (including last incorporations) in the Industry 4.E Lighthouse.

Regarding relevant roadmaps of other initiatives, the goal was to identify emerging topics in these roadmaps and topics not addressed in ECSEL MASP that could be also relevant in ECSEL. The analysis has been focused on how the four main challenges of Digital Industry of ECSEL MASP are addressed, while crosscutting aspects will be also addressed, both technical (cybersecurity, data availability, interoperability, etc.) and non-technical (standardization, regulatory aspects, etc.).

The ECSEL-JU projects that are part of the Industry 4.E Lighthouse (see Figure 1) have been analysed regarding the key application areas, the essential capabilities and the challenges for the Digital Industry that they address. The ECSEL projects that have been analysed are the following: Productive 4.0, MANTIS, SWARMS, SemI40, Delphi4LED, SCOTT, I-MECH, AFarCloud, IDev40, MADEin4 (new incorporation) and Arrowhead Tools (new incorporation).

[1] ECS SRA 2019 is available on ECSEL-JU website here: https://www.ecsel.eu/sites/default/files/2019-02/ECS-SRA%202019%20FINAL.pdf

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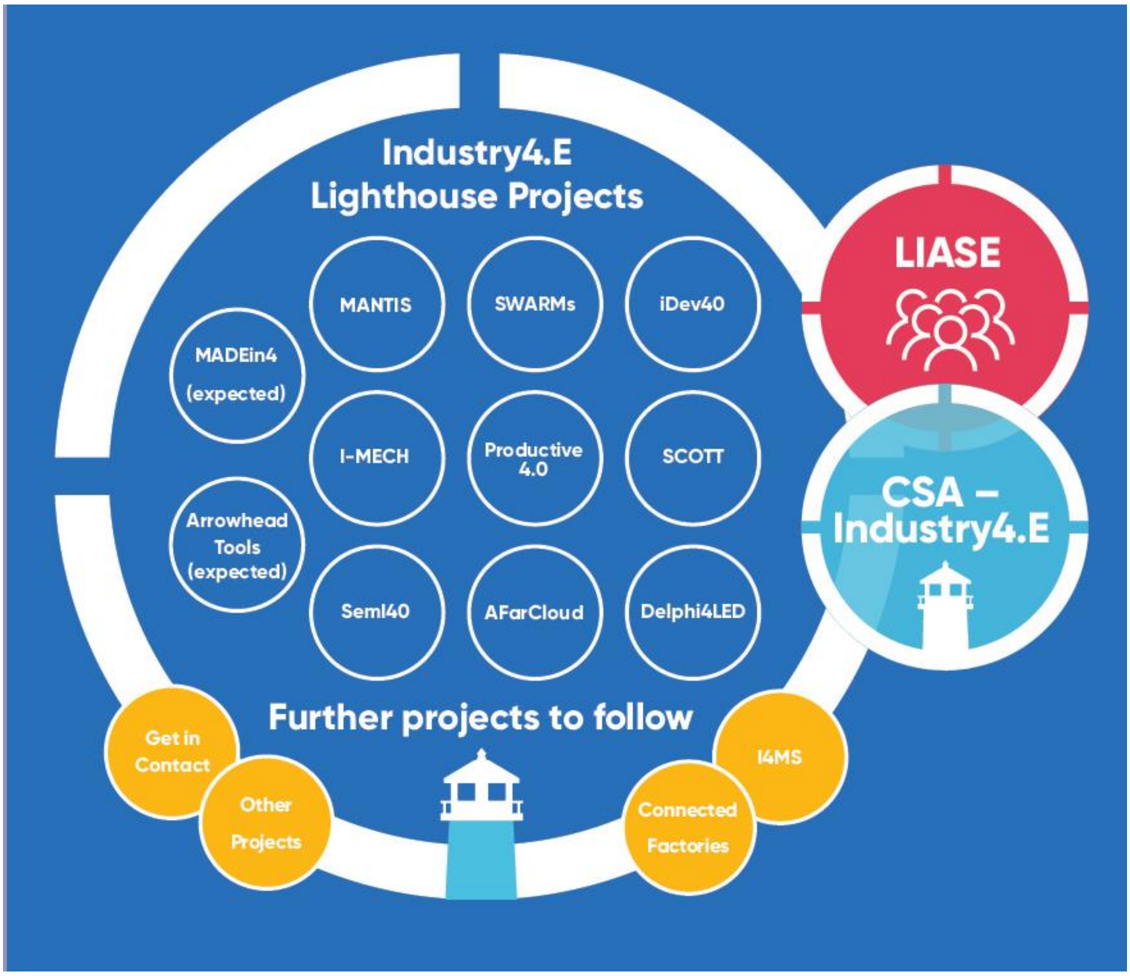

Figure 1: Industry4.E Lighthouse projects

In section 2, the roadmaps are analysed; first criteria for selecting and analysing the roadmaps as well as the selected roadmaps are presented, and later the analysis of these roadmaps is included. Section 3 presents a summary of the gaps identified after the roadmap analysis. In section 4, the Industry4.E Lighthouse projects are assessed: classification criteria are defined, a summary of each of the projects is presented, and the analysis is presented. Finally, section 5 presents some conclusions.

2 Roadmaps, strategic research agenda and visions

This section will define the criteria for selecting roadmaps, research agendas and visions that are relevant and the analysis of the selected roadmaps.

2.1 Criteria for selecting roadmaps

Three criteria have been defined for selecting the roadmaps, research agendas and vision to be analysed for the intermediate version.

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- Date of the documents: Only recent roadmaps/visions/strategic agendas will be analysed. The range of date between 2017-2019 has been selected.
- Topics: Roadmaps with focus on manufacturing plus roadmaps with focus on technological topics related to the challenges of Digital industry (data analysis, IoT/CPS, HPC, etc.) have been selected.
- Geographical scope: European roadmaps and a national initiative: German national industry 4.0 roadmap. Only the German roadmap has been selected as is the precursor of other national initiatives in Europe. International initiatives will not be analysed in the intermediate version of the deliverable. The world manufacturing forum is an exception as it is mainly Europe driven forum, given that the European Commission one of the partners.

2.2 Selected roadmaps

- EFFRA Roadmaps + Factories of the Future in Horizon Europe (2021-2027): Preparing the next multi-annual roadmap for Framework Programme 9, FoF in Horizon Europe – confidential – 12/2018
- European Roadmap for Industrial Process Automation, 2nd version (2018)
- Eureka Smart Advanced manufacturing Technology Roadmap (2018)
- Manufuture Vision 2030
- CPS Roadmaps (Platforms4CPS, Road2CPS and CPSoS)
- Big data: European Big Data Value Strategic Research and Innovation Agenda, BDVA, 2017 + "Big data challenges in smart manufacturing: A discussion paper on big data challenges for BDVA and EFFRA Research & Innovation roadmaps alignment" (March 2018)
- HiPEAC Vision
- The Industrie 4.0 (national/German) Roadmap/Guidelines and the associated Working Group Documents
- 2018 World manufacturing forum report: Recommendations for the future of manufacturing

2.3 Analysis of selected roadmaps

For the analysis, the challenges identified for the Digital Industry and the subtopics highlighted in the ECS SRA of ECSEL have been used, plus cross-cutting aspects and other topics relevant in ECSEL:

1-DIGITAL TWIN

- Light-weight general models
- Model connectivity (adaptative)
- Virtual commissioning

2- MACHINE LEARNING

- Edge ML
- Hybrid solution
- New CPU/GPU APIs
- 5G video stream & object detection

3 - CONDITION MONITORING

- NB-IoT sensors

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- Descriptive language
- 5G indoor location for remote support
- 5G real-time data analysis

4 - DIGITAL PLATFORMS

- Meta-platform
- Cross-Functionality
- Tools

5- Cross-cutting aspects present in ECSEL: Cyber-physical systems, IoT, SoS, Electronic Components and Systems, semicon, cyber-security, connectivity, interoperability, etc.

And for identifying emerging trends and potential gap with the ECSEL SRA a more general categorization is proposed:

- Design principles. The topics presented in [2] could be used as input (see Figure 2)
- Technology trends. The topics presented in [2] could be used as input (see Figure 2)
- Other aspects such as Paradigm shifts / impact aspects / drivers / social aspects…

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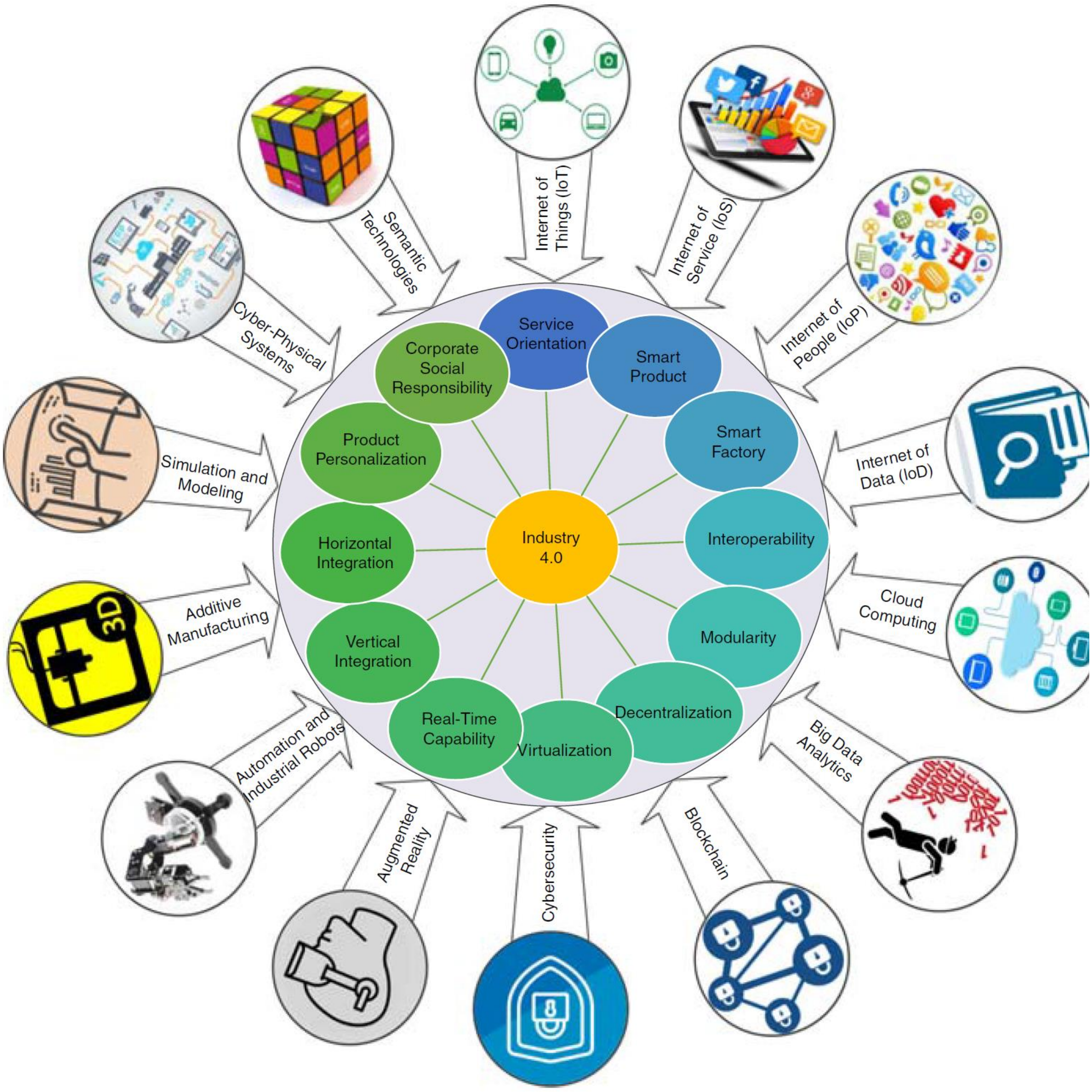

Figure 2: Design principles and technology trends of Industry 4.0, imaged taken from [2]

2.3.1 EFFRA: Factories of the Future in Horizon Europe (2021-2027)

2.3.1.1 Summary

The EFFRA's vision for Factories of the Future in Horizon Europe (2021-2027) presents 4 impact components, 4 key priorities under a common headline "Co-creation through Manufacturing Eco-systems" and 9 enabling technologies & Approaches (see Figure 3).

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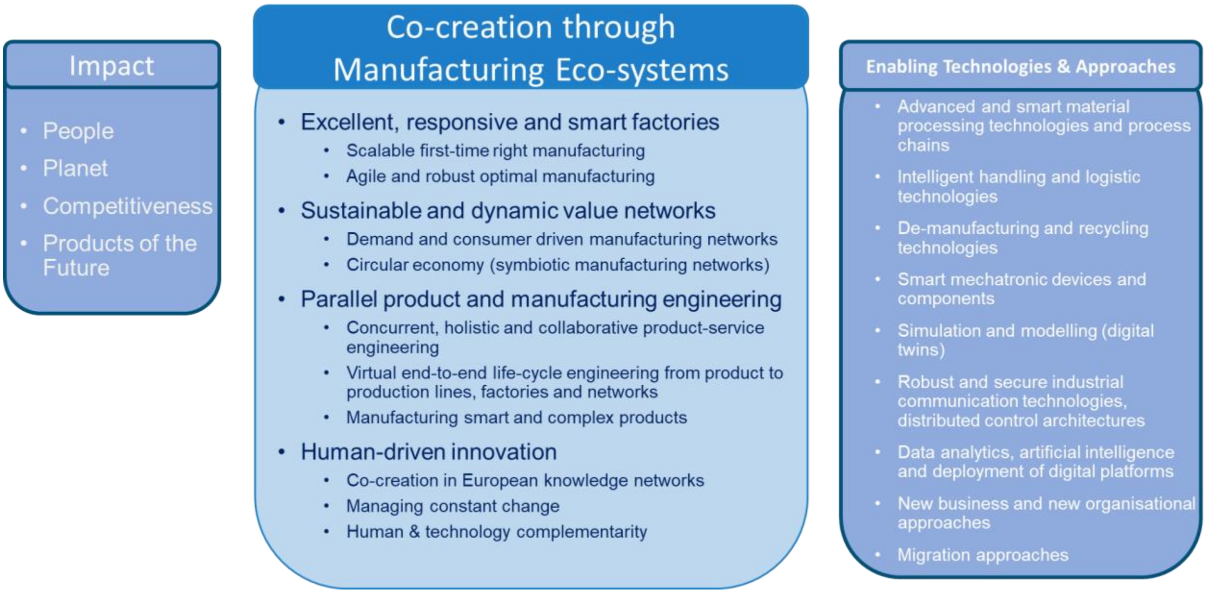

Figure 3: Impact components, key priorities and enabling technologies

4 main components of impact are mentioned:

- Competitiveness (Performance): Top quality, efficiency in terms of costs and resources, responsive to market and customer needs, creative and innovative solutions… → top priority
- People: Social innovations, digital skills, human-machine-relation, etc.
- Planet: Energy and resource efficiency, circular economy, low-footprint approaches…
- Manufacturing the Products of the Future: Opening/creating new markets, process and product innovation, etc. → More important than in FoF2020

Regarding the set of enabling technologies and approaches, 4 of them (in bold) are totally aligned with ECSEL technologies:

- Advanced and smart material and product processing technologies and process chains (additive, joining, assembly, shaping, structuring, etc…)
- Intelligent handling and logistic technologies
- De-manufacturing and recycling technologies, life-cycle analysis approaches
- **Smart mechatronic devices and components**
- **Simulation and modelling (digital twins) covering the material processing level up to manufacturing system, factory and value network level**
- **Robust and secure industrial real time communication technologies, distributed control architectures**
- **Data analytics, artificial intelligence and deployment of digital platforms for data management and sharing**
- New business and new organisational approaches, including links with regulatory aspects such as safety, data ownership and liability
- Migration approaches from as-is situation towards innovative solutions

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Moreover, "Hardware"-related technologies integrated with and complement by digital technologies and soft or organisational strategic enablers and approaches are considered the centre of manufacturing innovation and innovative products. Clear pointers to existing PPPs or initiatives that focus on particular enabling technologies are mentioned: photonics, **electronic systems and components**, 5G, Cybersecurity, Big Data and AI, Robotics, HPC, ….

In addition, the enablers related to electronic systems and components are important for almost all the key priorities with a high contribution (see Figure 4).

	Excellent, responsive		Sustainable and dynamic		Parallel product and manufacturing			Human-driven innovation		
	Scalable first-time right manufacturing	Agile and robust optimal manufacturing	Demand and consumer driven manufacturing networks	Circular economy (symbiotic manufacturing networks)	Virtual end-to-end life-cycle engineering from product to production lines, factories and networks	Concurrent, holistic and collaborative product-service engineering	Manufacturing smart and complex products	Co-creation in European knowledge networks	Managing constant change	Human & technology complementarity
Advanced and smart material and product processing technologies and process chains (additive, joining, assembly, shaping, structuring, etc...)	3	3	3	3	2	1	3			1
Intelligent handling and logistic technologies	3	3	3	3	2		3		3	3
De-manufacturing and recycling technologies, life-cycle analysis approaches	2	2	2	3	3	3	3	3	1	1
Smart mechatronic devices and components	3	3	2	1	3	3	2		1	3
Simulation and modelling (digital twins) covering the material processing level up to manufacturing system, factory and value network level	3	3	3	3	3	3	3	3	3	3
Robust and secure industrial real time communication technologies, distributed control architectures	2	3	3	3	3	3	3	3	3	2
Data analytics, artificial intelligence and deployment of digital platforms for data management and sharing	3	3	3	3	3	3	3	3	2	3
New business and new organisational approaches, including links with regulatory aspects such as safety, data ownership and liability	2	2	3	3	3	3	3	3	3	3
Migration approaches from as-is situation towards innovative solutions	3	3	3	3	3	3	3	3	3	3

Figure 4: Key priorities and enablers matrix

2.3.1.2 Analysis

The analysis has been made following the topics of the 4 challenges (and subtopic) of the digital industry chapter of the ECS SRA as well as cross-cutting aspects.

Digital twins, simulations (Challenge 1)

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The EFFRA roadmap mentions a technology enabler: “Simulation and modelling (digital twins) covering the material processing level up to manufacturing system, factory and value network level” that is totally aligned with the challenge 1 of the SRA.

This technology is an enabler for several focus actions:

- Focus Action 1.1: Scalable, reconfigurable and flexible first-time right manufacturing
- Focus Action 1.4: Predictive quality and non-destructive inspection methods for zero-defect manufacturing
- Focus Action 2.1: Simulation and communication technologies for circular economy
- Focus Action 2.2: De-manufacturing, re-manufacturing and recycling technologies for circular economy
- Focus Action 2.3: Mastering and tracing the product and production-lifecycle in a circular system
- Focus Action 3.2: Collaborative product-service engineering for costumer driven manufacturing value networks
- Focus Action 3.3: Virtual end-to-end life-cycle engineering from product to production lines, factories and networks
- Focus Action 4.2: Improving human device interaction using augmented and virtual reality and digital twins.
- Focus Action 4.4: New approaches and engineering tools supporting creativity and productivity of development processes (KP)

Regarding the sub-topics mentioned in the SRA: Light-weight general models, Model connectivity (adaptative) and Virtual commissioning

- Virtual commissioning is mentioned as enabler for Focus Action 1.1: Scalable, reconfigurable and flexible first-time right manufacturing

AI, machine learning, big data (Challenge 2)

The EFFRA roadmap mentions a technology enabler: “**Data analytics**, **artificial intelligence** and deployment of digital platforms for data management and sharing” that is much related to challenge 2 of the SRA.

This technology is an enabler for several focus actions:

- Focus Action 1.1: Scalable, reconfigurable and flexible first-time right manufacturing
- Focus Action 1.2: 5G in support of smart factories in dynamic value networks
- Focus Action 1.3: Artificial intelligence for productive, excellent, robust and agile manufacturing chains
- Focus Action 1.4: Predictive quality and non-destructive inspection methods for zero-defect manufacturing
- Focus Action 2.1: Simulation and communication technologies for circular economy

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- Focus Action 3.2: Collaborative product-service engineering for costumer driven manufacturing value networks
- Focus Action 3.3: Virtual end-to-end life-cycle engineering from product to production lines, factories and networks
- Focus Action 4.4: New approaches and engineering tools supporting creativity and productivity of development processes (KP)

Regarding the sub-topics mentioned in the SRA: Edge ML, Hybrid solution, New CPU/GPU APIs and 5G video stream & object detection.

- 5G is part of one of the Focus Actions: 1.2 5G in support of smart factories in dynamic value networks

Condition monitoring, decision making (Challenge 3)

This challenge is not mentioned explicitly but decision-making is related to data analytics, which is mentioned in a technology enabler (as already mentioned). Moreover, maintenance is related to quality and efficiency in the manufacturing.

Regarding the sub-topics mentioned in the SRA: NB-IoT sensors, Descriptive language, 5G indoor location for remote support and 5G real-time data analysis.

- 5G is part of one of the Focus Actions: 1.2 5G in support of smart factories in dynamic value networks

Digital platforms (Challenge 4)

The EFFRA roadmap mentions a technology enabler: “Data analytics, artificial intelligence and deployment of **digital platforms** for data management and sharing” that is much related to challenge 4 of the SRA.

This technology enabler has been already mentioned in relation to Challenge 2, as the technology enabler covers both AI and digital platforms.

Regarding the sub-topics mentioned in the SRA: Meta-platform, Cross-Functionality and Tools. The idea of Meta-platforms comes from EFFRA, as stated in the SRA, although this concept is not explicitly mentioned in the last roadmap.

Cross-cutting aspects present in ECSEL: Cyber-physical systems, IoT, SoS, Electronic Components and Systems, semicon, cyber-security, connectivity, interoperability, etc.

The EFFRA roadmap mentions two technology enablers: “Smart mechatronic devices and components” and “Robust and secure industrial real time communication technologies, distributed control architectures” that are very related to ECSEL topics.

“Smart mechatronic devices and components” technology is an enabler for several focus actions:

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- Focus Action 1.1: Scalable, reconfigurable and flexible first-time right manufacturing
- Focus Action 1.3: Artificial intelligence for productive, excellent, robust and agile manufacturing chains
- Focus Action 1.4: Predictive quality and non-destructive inspection methods for zero-defect manufacturing
- Focus Action 2.2: De-manufacturing, re-manufacturing and recycling technologies for circular economy
- Focus Action 2.3: Mastering and tracing the product and production-lifecycle in a circular system

"Robust and secure industrial real time communication technologies, distributed control architectures" technology is an enabler for several focus actions:

- Focus Action 1.1: Scalable, reconfigurable and flexible first-time right manufacturing
- Focus Action 1.3: Artificial intelligence for productive, excellent, robust and agile manufacturing chains
- Focus Action 2.4: Secure communication and IP management for smart factories in dynamic value networks
- Focus Action 2.6: Transparency, trust and data integrity along the product and manufacturing lifecycle
- Focus Action 3.2: Collaborative product-service engineering for costumer driven manufacturing value networks
- Focus Action 3.3: Virtual end-to-end lifecycle engineering from product to production lines, factories and networks

2.3.1.3 Emerging trends and potential gap with the ECSEL SRA

Design principles

Regarding design principles, the general trend is to further "leave the factory floor" and to look at "the bigger picture": the manufacturing eco-system and how co-creation takes place through the different actors involved. In this sense, the involvement of the human is mentioned as important. This involvement is not highlighted in the ECSEL SRA.

Human driven innovation is a priority. And inside it:

- Human & technology complementarity is a priority. There is a focus in human & technology complementarity and excellence in manufacturing.
- Co-creation through Manufacturing Eco-systems is a priority.

Social innovation is also mentioned inside the next enabler: Migration approaches from as-is situation towards innovative solutions (blending social innovation and technological innovation).

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Technology trends

Regarding the technological trends, this roadmap mention topics such as Human-device interaction, Virtual and Augmented reality that in the ECSEL SRA are barely mentioned. In EFFRA's roadmap there is a focus action regarding that: Focus Action 4.2: Improving human device interaction using augmented and virtual reality and digital twins.

Related to human-driven innovation, new engineering tools supporting creativity are mentioned in Focus Action 4.4: New approaches and engineering tools supporting creativity and productivity of development processes (KP).

Paradigm shifts / impact aspects / drivers / social aspects

Skills related challenges are mentioned and that the need for adequate skill sets in manufacturing has kept growing is mentioned as well.

Sustainable manufacturing and circular economy have a great importance in the roadmap. With the key Priority 'Sustainable and dynamic value networks' and focus actions:

- Focus Action 2.1: Simulation and communication technologies for circular economy
- Focus Action 2.2: De-manufacturing, re-manufacturing and recycling technologies for circular economy

The ECS SRA is not addressing those topics explicitly.

2.3.2 European Roadmap for Industrial Process Automation, 2nd version (2018)

2.3.2.1 Summary

This analysis is based on European Roadmap for Industrial Process Automation second version, 2018.

ProcessIT.EU value proposition is as follows:

1. Accelerate growth and technology development in Europe through increased competitiveness in related industries and research organizations.
2. Strengthen the competitiveness of process industries through innovations in ICT and automation technology.
3. Strengthen automation technology suppliers through the incubation and implementation of strong R&D projects that innovate and develop globally competitive automation solutions.
4. Support the European automation research community in further developing world-class research by providing access to highly challenging industry contexts and involvement in leading innovation projects.

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ProcessIT.EU identifies top-level needs and industrial automation R&D areas as follows:

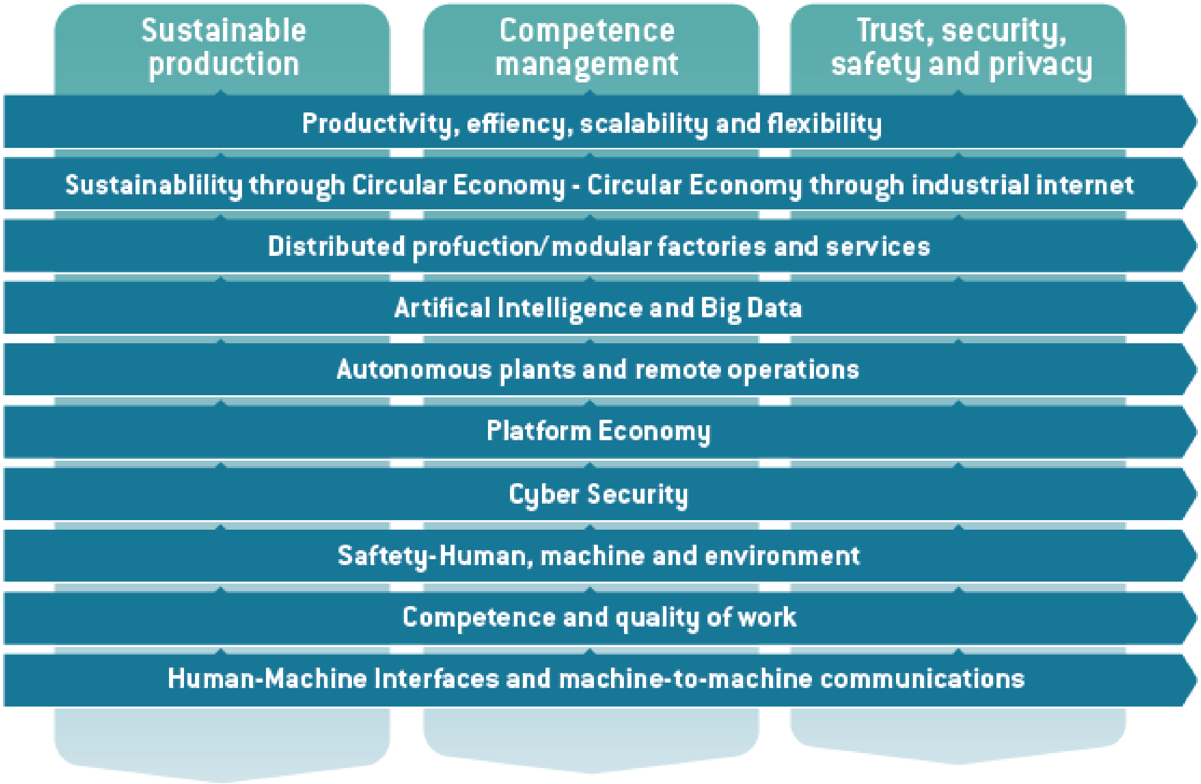

Figure 5: Top level needs and R&D areas

In addition to R&D areas, ProcessIT.EU roadmap also identifies game changers for competitiveness, as follows:

1. Modular factory for distributed and automated production
2. Live virtual twins of raw-materials, process and products
3. Increased information transparency between field and EPR
4. Real-time data analytics
5. Dynamic control and optimization of output tolerances
6. Process industry as an integrated and agile part of the energy system
7. Management of critical knowledge
8. Semi-autonomous automation engineering
9. Integrated operational cybersecurity management

For each game changer, the roadmap further describes the impact on competitiveness and which R&D areas are linked to which game changer.

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2.3.2.2 Analysis

Analysis is twofold, first we identify how ECS SRA major challenges are addressed in ProcessIT.EU R&D areas and second, we make a comparison table between ProcessIT.EU game changers and how they relate to the ECS SRA 2019.

Digital industry major challenges

Major challenge 1: Developing digital twins, simulation models for the evaluation of industrial assets at all factory levels and over system or product lifecycles

- Simulators and modelling are identified trends in "Productivity, efficiency, scalability and flexibility" R&D area
- Digital twins are addressed in "Productivity, efficiency, scalability and flexibility" R&D area in goals and vision: "Sustainable virtual factory/twin - automatic and data-driven"
- Complex system simulations and optimisation is seen as requirement and trend for "Sustainability through Circular Economy" R&D area
- Simulation of extended/distributed production processes is seen as an identified trend in "Distributed production" R&D area. Virtualisation and simulations are seen as key technologies for achieving distributed production process.
- In "Cybersecurity" R&D area simulations use for training and recovery action planning is an identified trend. It also has as a goal that cybersecurity aspects should be integrated in design and simulations models to enable risk evaluations
- In "Safety - Human, machine and environment" R&D area has a goal that safety aspects must be integrated in the simulation models
- Modelling and simulations are seen as technology to train operators and other personnel in "Competence and quality of work" R&D area
- Augmented reality (as well as virtual) is seen in one of the identified trends in modelling and simulations in "Human-Machine Interfaces and Machine-to-Machine Communications" R&D area.

Major challenge 2: Implementing AI and machine learning to detect anomalies or similarities and to optimise parameters

- Roadmap has one R&D area for "Artificial Intelligence and Big Data". Artificial intelligence impact is seen on specific targeted AI systems with several use cases. Service business and AI is seen as next a big opportunity. Goal is that AI will have strong impact in decision-making.
- HMI is one identified trend as well as gamification (AI related such as reinforcement learning) in "Competence and quality of work" R&D area.

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- Well-defined M2M communications are seen as an enabler to machine learning in process automation in "Human-Machine Interfaces and Machine-to-Machine Communications" R&D area.

Major challenge 3: Generalising condition monitoring, to pre-damage warning on-line decision-making support

- Predictive- and condition- based maintenance optimisations is one of the identified trends in "Productivity, efficiency, scalability and flexibility" R&D area.
- Predictive maintenance is seen as one of the use cases for artificial "intelligence and big data" R&D area.
- Predictive- and condition-based maintenance are seen as key technologies to ensure safety in "Safety - Human, machine and environment" R&D area. In this area, one goal is well-developed predictive condition monitoring system to detect machine degradation.

Major challenge 4: Developing digital platforms, application development frameworks that integrate sensors and systems

- ProcessIT.EU roadmap has a R&D area "Platform Economy" that deals specifically with digital platforms. Identified trends include B2B platforms, increased use of IoT platforms, enhanced connectivity, platform interoperability (vendor neutral), data value sharing mechanisms and open specifications and interfaces.
- In "Productivity, efficiency, scalability and flexibility" R&D area advanced lifecycle management and collaboration functionality is identified as a need for production process platforms.
- Enabling new tool chains with integration of legacy systems is seen as one goal in "Distributed production" R&D area.

Cross-cutting aspects

The ProcessIT.EU roadmap does not separate R&D areas between technical and cross-cutting, but it identifies a set of top-level needs as follows:

- Sustainable production
    - Circular economy
    - Environmental security, physical security and safety
    - Incentives for responsible/sustainable production and operations
    - Managing profitability and investments
    - Overall equipment efficiency (OEE)
    - Overall cost versus quality and RDI-efforts
    - Managing and improving quality
    - Business models
    - Accountability

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- Competence management
  - Long-term perspective
  - Invest before needed
  - Experience
  - Risk management
  - Changing demography
  - Cost level per work hour versus automation
  - Retirements and need for trained and highly educated workforce
  - New tools, methods and processes require continuous training and a further advanced skill set
  - Knowledge management - convert tacit to formal knowledge
  - Outsourcing from large companies to small companies

- Trust, cybersecurity, safety and privacy
  - Risk management
  - Cybersecurity (including IT-/OT-/information security, etc.)
  - Access to production and automation data, authentication and authorization
  - Ownership of data
  - Availability
  - Confidentiality
  - Integrity and accuracy
  - Usability
  - Non-repudiation (digital signatures/blockchains)
  - Incident management, disaster recovery and business continuity
  - Safety and liability

Game changers

In the ProcessIT.EU roadmap, several game changers are identified. The following table shortly describes their relationship to the Digital Industry major challenges (MC):

Addressed = Referred in game changer text section.

Related = Referred in associated R&D areas (AI and big data / platform economy).

ProcessIT.EU game changer / ECS SRA 2019 major challenge	ECS MC 1: digital twins, simulations	ECS MC 2 AI and machine learning	ECS MC 3 condition monitoring	ECS MC 4 digital platforms
Modular factory for distributed and automated production	Addressed	Related		Related
Live virtual twins of raw-materials,	Addressed	Related		

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process and products				
Increased information transparency between field and ERP			Addressed	Related
Real-time data analytics		Related	Addressed	
Dynamic control and optimization of output tolerances		Related	Addressed	
Process industry as an integrated and agile part of the energy system		Related (addressed as an increased integration requirement)		
Management of critical knowledge		Related (addressed as a management need for AI and big data decision-making)		
Semi-autonomous automation engineering		Related		
Integrated operational and cybersecurity management		Related		

2.3.2.3 Emerging trends

In the game changers, ProcessIT.EU roadmap identifies two R&D areas, namely Artificial Intelligence and Big Data, and Autonomous Plants and Remote Operations that are associated with long-term timeframe in game changers.

ProcessIT.EU roadmap describes identified trends throughout each R&D area, some emerging trends that can be identified from descriptions, include:

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- Data preservation/availability as amount of data collected and stored increases taken also into consideration metadata from external sources
- New sustainable business models: Product-Service Systems (PSS), Industrial Product-Service Systems (IPS2) and functional provisions.
- Personalised and targeted B2B marketing, smart contracts
- Service business around artificial intelligence
- In the long term, artificial intelligence is expected to bring transformative changes
- New emerging business models for platform economy
- Novel HMIs and sensor systems

2.3.3 Eureka Smart Advanced manufacturing Technology Roadmap (2018)

2.3.3.1 Summary

The Technology Roadmap of SMART: Advanced Manufacturing Eureka Cluster illustrates the technology areas and developments that are needed to take a big step in the competitiveness of the manufacturing industry in Europe.

The SMART Technology Roadmap is developed based on three building blocks:

1. The industrial challenges that manufacturing companies face with the gaps, barriers and bottlenecks that they need to overcome in order to improve their competitiveness. The challenges have been identified in several high impact industrial sectors: Aeronautic, Automotive, Consumer Goods, Capital Good and Railway.
2. The enabling technologies and trends that are pushing forward the development capabilities, which will be basic to develop innovative solutions. The Enabling Technologies are the following areas: Material Processing Technologies; Mechatronic Technologies and Systems; Flexible, Adaptive and Collaborative Robotics; Information and communication technologies and Production Technologies
3. Finally, based on the two previous blocks, 6 research and innovation domains are defined to address the industrial challenges, and that are further divided into specific topics. The 6 domains are:

    1. Advanced Manufacturing Processes, including innovative processing for either new and current material or products.

    2. Intelligent and Adaptive Manufacturing Systems, including Innovative Manufacturing equipment at components and system levels, mechatronics, control and monitoring systems

    3. Digital, Virtual and Efficient Companies, including Factory design, data collection and management, operation and planning, from real time to long term optimization approaches

    4. Person-Machine Collaboration, including the enhancement of the role of people in manufacturing

    5. Sustainable Manufacturing, including innovative processes and systems for sustainability in terms of energy and resource consumption and impact in the environment.

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6. Customer-based Manufacturing, including involving customers in manufacturing value chain, from product process design to manufacturing associated innovative services

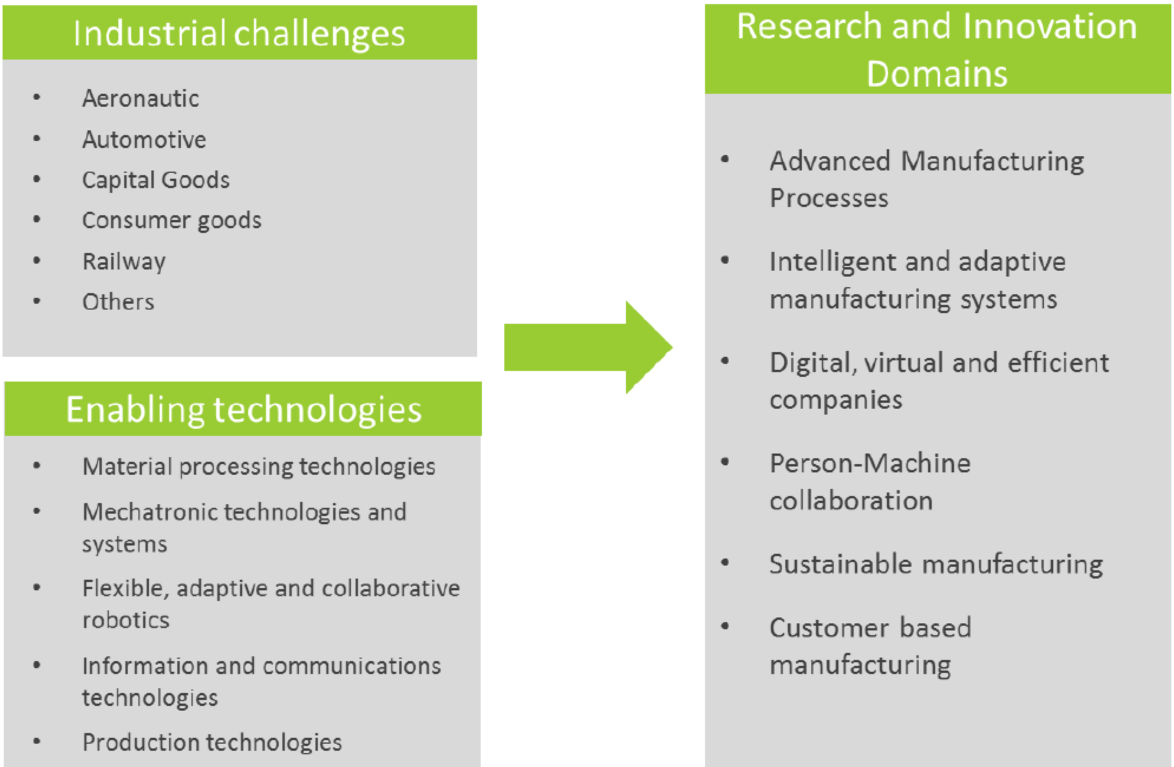

Figure 6: Industrial challenges, enabling technologies and research and innovation domains from SMART roadmap

2.3.3.2 Analysis

The analysis has been made following the topics of the 4 challenges (and subtopic) of the digital industry chapter of the ECS SRA as well as cross-cutting aspects.

Digital twins, simulations (Challenge 1)

Regarding this challenge, modelling and simulation is a topic mentioned several times in the SMART technology roadmap inside different research and innovation domains:

- **Advanced modelling and simulation tools for manufacturing process design and optimisation, including machine-process interaction** inside the “Advanced Manufacturing Processes” research and innovation domain
- **Multi-disciplinary simulation tools for mechatronics engineering** inside the “Intelligent and Adaptive Manufacturing Systems” research and innovation domain.
- **Simulation techniques in manufacturing and assembly processes to increase ergonomics, first-time-right and production rates** inside the “Digital, Virtual and Efficient Companies” research and innovation domain.

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- **Comprehensive modelling and simulation tools. Cost models linked to design, productivity, end of life and recycling** inside the “Digital, Virtual and Efficient Companies” research and innovation domain.
- **Simulation, concurrent engineering methods and prototyping technologies for shortening development and certification cycles** inside the “Customer-based Manufacturing” research and innovation domain.
- **Rapid prototyping techniques cycles** inside the “Customer-based Manufacturing” research and innovation domain.

AI, machine learning, big data (Challenge 2)

Regarding data (related to this challenge as well as challenge 3) the topics of **use of big data and evolutionary algorithms for processes diagnosis, monitoring & control as well as predictive maintenance** and **“End to End” data backbone for complete integration of production processes** inside the “Digital, Virtual and Efficient Companies” research and innovation domain in SMART technology roadmap are related to this challenge. Data collection and management is mentioned in this domain as well.

Regarding cognitive services and intelligence, the research and innovation domain “Intelligent and Adaptive Manufacturing Systems” is also very related as well as the following two topics in this domain:

- Sensors for process diagnostics, and process monitoring and visualisation, integrated with cognitive systems for intelligent and self-optimising production equipment
- Integration of cognitive functions into machines and robots for adaptability to changing manufacturing requirements.

Condition monitoring, decision making (Challenge 3)

Monitoring and monitoring systems are part of the research and innovation domain “Intelligent and Adaptive Manufacturing Systems” with the following topics:

- Advanced on-line processes **monitoring** and control systems. Development of measurement systems, sensors and indicators algorithms for process diagnosis and optimization.
- Sensors for process diagnostics, and process **monitoring** and visualisation, integrated with cognitive systems for intelligent and self-optimising production equipment
- **Monitoring** and optimization of machines and equipment in real time. Advanced metrology

Maintenance is also explicitly mentioned in the following topics:

- **Predictive and proactive maintenance** systems based on advanced sensor information and processing inside “Intelligent and Adaptive Manufacturing Systems” research and innovation domain
- Use of big data and evolutionary algorithms for processes diagnosis, monitoring & control as well as **predictive maintenance** inside the “Digital, Virtual and Efficient Companies”

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Digital platforms (Challenge 4)

Digital platforms are not explicitly mentioned in the SMART technology roadmap but data acquisition, storage and processing as well as secure, high performance and open communications and platforms are mentioned, as well as multi-platform solutions.

Regarding topics in the research and innovation domains, the ones mentioning integration are the following:

- **"End to End" data backbone for complete integration of production processes** inside the "Digital, Virtual and Efficient Companies" research and innovation domain
- **Multidisciplinary technologies integration for the complete life-cycle optimisation of production systems** inside "Intelligent and Adaptive Manufacturing Systems" research and innovation domain

Cross-cutting aspects present in ECSEL: Cyber-physical systems, IoT, SoS, Electronic Components and Systems, semicon, cyber-security, connectivity, interoperability, etc.

Some of the research topics mentioned in the SMART technology roadmaps that are relevant for ECSEL are the following:

- Advanced sensor system, multi-sensor fusion
- Cybersecurity and secured concepts for communications and cloud computing
- Concepts for safe automation of operations and of system integration
- Towards manufacturing as a service and additional services for manufacturing operation support

2.3.3.3 Emerging trends

Design principles

Regarding design principles, two of the research and innovation domains of SMART technology roadmaps are not pinpointed in ECSEL SRA:

- Person-machine collaboration, related to the enhancement of the role of people in manufacturing: developing inclusive workplaces, with high interaction capacity, easy to operate and safe for persons. And topics such as
    - Friendly and inclusive work environments (noises, emissions, vibrations, loads, repetitive tasks, ergonomics).
- Customer-based manufacturing: Involving customers in manufacturing value chain, from product process design to manufacturing associated innovative services. And topics such as
    - Modular systems, reconfigurable machines and processes for efficient adaptation to customer demands

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- Customisation of products and processes

Technology trends

Regarding the technological trends, this roadmap mention topics related to

- Robotics and human-robot collaboration:
    - Robotic toolbox including light automation and collaborative robotics
    - New machine architectures, including collaborative integration of robots for flexibility and multi-processing capabilities.
    - Intuitive programming devices, aimed at multimodal tasks and based on new dialogues between humans, machines and robots
    - Ergonomic human-robot collaboration, for Human performance improvement and error minimisation. Coexistence of robots integrated with manual processes.
- Visualization: Human-Machine interfaces (HMI), Virtual and Augmented reality:
    - Concepts for smart use of IoT, virtual or augmented reality improving operations/process flow visualization systems. Improved visualisation and analysis of complex production flows
    - Advanced operator information systems, production and process model-based systems to support operator decisions
    - Augmented and immersive reality for fast training, secure and efficient operation
    - Virtual reality and augmented reality simulators for planning and operation of manufacturing systems
- Inspection, artificial vision, metrology. And the use of complementary technologies such as **optics** and **photonics**. With topics such as:
    - Advanced non-contact, vision-based parts on-line measurement in manufacturing processes
    - Advanced automated non-destructive inspection operations (NDT) on-line inspection for zero defects manufacturing

The SMART technology roadmap also mentions the coexistence of photonics and robotics with advanced manufacturing processes in industrial environments.

In the ECSEL SRA, robotics as well as AR/VR/MR are mentioned, and their use seen as an opportunity. AR/VR/MR is also considered a game changer. However, research in those topics is not addressed.

Paradigm shifts / impact aspects / drivers / social aspects

There is a research and innovation domain related to sustainability in the SMART technology roadmap: Sustainable manufacturing: Innovative processes and systems for sustainability in terms of energy and resource consumption and impact in the environment.

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2.3.4 Manufuture Vision 2030

2.3.4.1 Summary

The ManuFUTURE Vision 2030 presents an analysis of the manufacturing industry today, megatrends and drivers for manufacturing, and challenges as well as opportunities for European manufacturing. The last three chapters present the ManuFUTURE Vision and strategy for 2030, a total of three ManuFUTURE Vision building blocks, and manufacturing and society. Starting from a strong scientific and technical leadership, the ManuFUTURE Vision evolved over time. Moving from a pure focus on ensuring competitiveness in its early days, to the inclusion of sustainability requirements, the 2030 Vision addresses now also the need for a resilient and adaptive manufacturing ecosystem able to cope with increasing levels and environmental and social requirements.

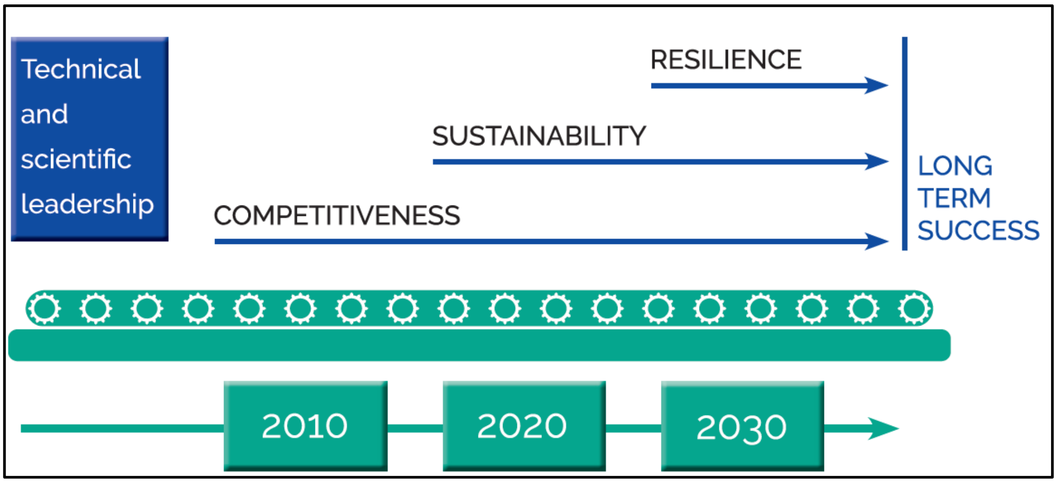

Figure 7: High-level vision for European manufacturing 2030

Four areas are analysed within the manufacturing industry today:

- European Manufacturing
- Global position
- Manufacturing strategies and programmes at global level (USA, China, Japan, South Korean)
- New world scenario – global competition and cooperation and the role of STI (science, technology, and innovation)

Regarding megatrends and drivers for manufacturing, 4 main megatrends with in total 10 subordinated trends mentioned:

- Political and Environmental
  - Uncertain global political environment
  - Climate change and scarcity of natural resources
- Economic
  - Fierce competition going up the value chain
  - New business models and global value networks
- Social

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  - Changes in demographics: Increase in the middle class, urban and aging population
  - New consumer preferences and environmental awareness
  - New skills and employment patterns
- Technological
  - Accelerated technological progress and adaption
  - Global access to knowledge
  - More complex products, processes and value networks

To respond to the megatrends and drivers identified, ManuFUTURE presents eight challenges and opportunities for European manufacturing, which are the following:

- Customer-centric value creation networks
- Leapfrog productivity gains through technology intelligence
- HUMANufacturing as a new era of automation
- Simplexity – Making complex manufacturing systems simple
- Responsible value creation in a circular economy
- New partnerships for new manufacturing skills
- Manufacturing as networked and dynamic sociotechnical system
- Value creation networks

In terms of the ManuFUTURE vision the key long-term vision is that 'European manufacturing in 2030 will be a globally competitive, interconnected and adaptive sociotechnical value creation system that ensures sustainable growth and social welfare, in a resource constrained world'. To aiming at long-term competitiveness and success, the ManuFUTURE Vision for 2030 proposes that Europe needs to build on its proven capabilities and invest more to ensure its leadership in:

- Key enabling technologies
- Digital transformation and new business models
- Mastering complexity of products, processes and systems
- Resource efficiency and sustainable development
- Resilient and adaptive manufacturing
- Innovation ecosystem

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Figure 8: **ManuFUTURE Vision and strategy**

In addition, to achieve the Vision and Strategy ManuFUTURE defines three building blocks: science and technology, innovation and entrepreneurship, and education and training. Within the first building block the focus is on Applied Research, Fundamental Research, and Social Sciences and Humanities, whereas the other chapters gives recommendations in terms how to create a European manufacturing qualification and training program, how to enabling technologies for reshaping manufacturing education and training in Europe, and regarding merging manufacturing education paradigms (e.g. The Teaching / Learning Factory).

2.3.4.2 Analysis

The analysis has been made following the topics of the four challenges of the digital industry chapter of the ECSEL SRA as well as cross-cutting aspects.

<u>Digital twins, simulations (Challenge 1)</u>

In regard to the challenge of digital twins and simulation, the ManuFUTURE report identifies that "novel digital/physical architectures will emerge", and that these technologies will allow for more integration between factory network levels, so that they will have more flexibility and responsiveness. It further defines that **ICT for cyber-physical manufacturing** "encompasses the use of sensors to collect data in the real world, together with intelligent control and mechatronics, increased amounts of available data, information and knowledge", which **enables detailed digital twins for machines, production lines and complete factories**. Further elaboration on the topic of simulations as a tool for Industrie 4.0 was not made in this report.

<u>AI, machine learning, big data (Challenge 2)</u>

On the topic of AI, machine learning, and big data, ManuFUTURE report claims that AI will soon be widely adopted, and will be able to support product design, operations, decision-making and customer

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interaction. The report also predicts that future factories will "adapt and become resilient to foreseen and unforeseen changes in the market and in technology" as a result of AI and machine learning. Moreover, the report discusses the importance of **Humanufacturing**, a concept which involves augmenting relevant human capabilities with new technologies.

The ManuFUTURE report also advocates that new business models will create a new ecosystem of global values networks; that the power of AI will be harnessed to allow for companies to better understand their market. The publication envisions that data itself will become a revenue source, and that European actors will need to utilise new technology systems like AI to grow business in new sectors. It attributes that the fast-growing development and adoption of **AI** and **Virtual Reality** based applications for product and process development, combined with increasingly lower cost of equipment and services for additive manufacturing, empower customers to develop and, eventually, produce conventional and new products. It also advocates that **more investment should be made in AI**, as it is a Key Enabling Technology (KET), and it asserts that new business models and logic can be reaching on this topic through applied research.

With the advent of huge amounts of information now available from **AI, machine learning, and big data**, the ManuFUTURE Vision roadmap highlighted that there is a big potential in leapfrogging productivity gains in engineering and manufacturing processes by using technology intelligence provided by **machine learning, modelling, simulation**, among other technologies. Huge amounts of data from multiple sources must be collected, processed and analysed to provide the right products and services at the right time and at the right place.

Specifically for **artificial intelligence**, the publication envisions that it will be widely adapted to **product design, operations, decision-making and customer interaction**. With this, factories will adapt and become resilient to foreseen and unforeseen changes in the market and in technology. Furthermore, the ManuFUTURE roadmap states that "AI will enable the extraction of knowledge from the huge amounts of data generated and captured at all levels from **consumer behaviour, product utilisation, manufacturing and global supply networks**", while simultaneous **supporting human activities** of **analysis, decision-making, and considering uncertainties**. It aims that new generations of products and new manufacturing protocols emerge from this knowledge.

The Vision points out that AI will enable increased levels of automation and human interaction, while cyber security will be a prerequisite for global collaboration and interaction.

Condition monitoring, decision making (Challenge 3)

When it comes to condition monitoring and decision making, as well as the subtopics of IoT data sensors and 5g real-time data analysis, these topics were not as comprehensively discussed in this report. However, under the context of **resilience**, ManuFUTURE states that through the **constant and continuous monitoring** of the environmental change, **advanced IT platforms** can provide business intelligence and **advanced decision-making**. It added that value networks and new manufacturing paradigms will emerge like cloud- and edge-based manufacturing.

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In regard to the cross-cutting concept of education for this sector, the report listed several goals for manufacturing education. Namely, it defines "addressing non-technological skills, perception and behaviour abilities, such as the capacity for understanding complex situations, awareness, proactivity, problem solving, **decision making**, leadership, team spirit, entrepreneurship and communication in multiple languages" as key components to prepare the next generation for work in this sector.

Digital platforms (Challenge 4)

The ManuFUTURE roadmap points out that **digital platforms** support product **design and development**, possibly including the **end consumer**, and **operations management**. The report specified that digital platforms can be utilized for "**storage of sensor data** and **traceability in blockchains** as well as the **cyber security**, including privacy protection will gain significant importance in manufacturing." Moreover, advanced IT platforms will provide **business intelligence** and **advanced decision-making**.

The ManuFUTURE publication outlines that digital platforms "providers assemble temporal limited process chains and allow traditional companies to better orchestrate their business, grab new business opportunities and implement new business models." The ManuFUTURE roadmap speaks widely about the importance of creating regional value global markets. It visualises that European regions with many leading "hidden champions" in the technology sector could be a player in developing **platform structures for SMEs** that focus on efficiency and intelligence. The report also envisions that "platform manufacturing, engineering, logistic and service companies will interact supported by interoperable systems and **open standards**", which would make it possible for complex production in the future to reach unprecedented levels of agility, modularity, resilience, and flexibility, while enabling the implementation of new business models and manufacturing strategies.

The Vison of new business models including the "Dynamic Virtual Value Networks" discusses **platform-based ad-hoc value networks,** which emerge spontaneously to match specific business opportunities at global level. Manufacturing companies of different sizes and service providers offer their **skills and capacities on the platform**. Each agent can set up a manufacturing network to produce and sell a defined batch of a specific product.

Cross-cutting aspects present in ECSEL:

The ManuFUTURE report refers to several cross-cutting themes within further areas of development of industry 4.0. It references to augmented reality (AR), simulation, **integration**, **industrial Internet**, cloud computing, **cybersecurity**, and flexible automation as major developments of the ongoing 4th Industrial Revolution, and pointed out that "digitalisation provides the means to address challenges such as mass customisation, lot-size-one production, re- and de-manufacturing and zero-defect manufacturing and enables continuous improvement in flexibility, productivity, accuracy, **security** and **sustainability**." It calls for **international standardisation** on all levels in order to maintain the knowledge of multi systems, especially for SMEs.

Lastly, the ManuFUTURE report clearly outlines what it considers as expected achievements for the sector at large. These consist of Europe being at the forefront of **circular economy** implementation,

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the establishment of a resilient and adaptive manufacturing ecosystem, and for Europe to provide leadership in **resource efficiency** and **sustainable development**. The report names specified several tools and recommendations to achieve these visions, including contributions from Applied Research, Fundamental Research, and Social Sciences and Humanities areas. In particular regard to ECSEL SRA cross-cutting themes, it recommends the following stepping stones to reach its vision:

2.3.4.3 Emerging trends and potential gap with the ECSEL SRA

Within this text, several important **Emerging Trends** identifies, under the two umbrellas of 'Technological' and 'Innovation related':

Technological:

- **Resilient factories** (flexible, adaptable, AI supported); resilient adaptive manufacturing ecosystem
- **Responsible value creation in a circular economy:** circular economy, resource and energy, track-and trace (cradle to cradle), optimisation of whole manufacturing ecosystem resources
- **Human centred manufacturing**: support human activity and augment their capabilities to higher levels of effectiveness and value added, new interfaces between humans and machines and also between machines will enable new levels of cooperation, **HUMANufacturing** combination for highly automated and robotised processes, yet capable of providing flexibility and adaptability to new customer requirements.
- **Platforms** for storage of sensor data and **traceability of transactions in blockchains** as well as the cyber security, including privacy protection

As the results of a **SWOT** analysis conducted in the ManuFUTURE report, several other cross-cutting topics with ECSEL emerged in the Opportunities and Threat section. **Opportunities** identifies include:

- Empowerment of customer in value creation via grids or webs
- Nature-inspired manufacturing
- Circular economy cooperation
- Job opportunities for young people- Learning/Teaching Factory Model

Innovation related:

- **New business logics and models:** customer centric value creation networks, socio-technical system, dynamic virtual platform-based ad-hoc value networks, maker economy, sharing economy, outcome economy, co-creation
- **Balanced and sustainable ecosystems** (customer centric and environmental aware, open)
- **Innovation and Entrepreneurship**
- **Skills and Training**
- **Contributions from Social Sciences and Humanities,** law, political sciences, and ethics
- **Manufacturing and Society**

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2.3.5 CPS Roadmaps (Platforms4CPS, Road2CPS and CPSoS)

2.3.5.1 Summary

The Platforms4CPS 'CPS Community Roadmap Report' summarises the findings from the project and of nine Cyber-Physical System (CPS) related roadmaps. The report presents a common view on future research priorities, barriers and enablers as well as recommendations for CPS related development and deployment activities. The aim of the document is to give an overview on the results and perspectives of recent and ongoing CPS-related roadmaps, analyse converging visions and to obtain consensus between main stakeholders in terms of required future actions across Europe. The following roadmaps in the field of Digitising European Industry have been compared:

- National Roadmap Embedded Systems - NRMES (2009)
- AgendaCPS (2012)
- Road2SoS (2014) CyPhERS Roadmap (2015)
- CPSoS Roadmap (2016)
- Road2CPS Roadmap (2017)
- PICASSO (2017)
- ARTEMIS-SRA (2016)
- ECSEL-MASRIA (2017)
- ECS-SRA (2018)

Moreover, the report identifies Research and Technology Priorities as well as Non-Technological Priorities and Innovation Accelerators, and building Consensus Roadmap Themes in eight key **technological domains** that capture new emerging themes within CPS:

- Data analytic and decision support
- Autonomy and robotics
- CPS Engineering
- CPS Architectures
- CPS Platforms
- Safety, security, privacy, trust
- Human as part of the system
- Communication and computing

In addition, the report presents themes for Future Research and Innovation Programmes, including trends (e.g. autonomous systems, Artificial Intelligence, and trust) and emerging research themes (e.g. edge computing, humans as an integral part of the system). Finally, the report gives recommendations, for research priorities in Horizon 2020, in short and Horizon Europe in long term perspective. The project involved a vast number of experts (mainly CPS related roadmap leaders) in interactive workshops to discuss and define future research and innovation priorities. They jointly worked on a so-called technology radar (see Figure 9), to visualise future developments.

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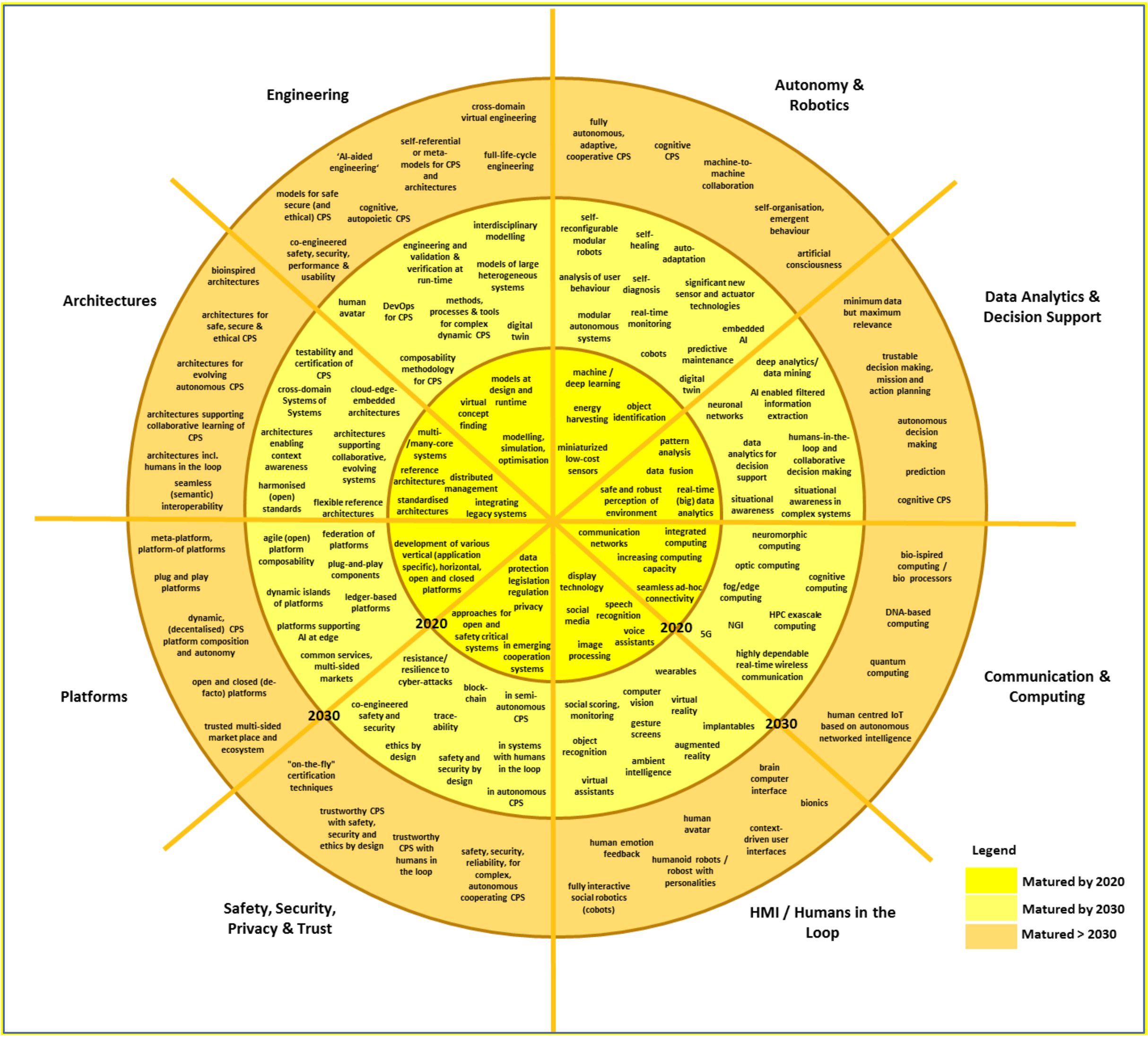

Figure 9: **Platforms4CPS technology Radar**

Results of analysis in the report indicate that important priorities to support successful CPS implementation were highlighted to be:

- Collaboration across initiatives, engineering / application domains, international collaboration
- Access of SMEs, start-ups and scale-ups to the ecosystem
- Openness, open data, open innovation and open platforms
- Demonstration, pilot lines and living labs
- CPS enabled business models and business services
- CPS standardisation, regulation, liability, privacy and ethics
- T-shape, cross-disciplinary education, lifelong learning and (re-/up-) skilling
- Raise awareness, promote societal dialogue, enhance user acceptance and trust
- Create a positive vision and respective plan for CPS developments and implementation

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2.3.5.2 Analysis

The analysis has been made following the topics of the four challenges of the digital industry chapter of the ECSEL SRA as well as cross-cutting aspects. The Platforms4CPS Roadmap focusses on Cyber-Physical Systems (CPS) which have already broadly entered the manufacturing sector as **Cyber-Physical Production Systems (CPPS)**. The CPS Roadmaps consist of three other important publications that are a result of collaborative initiatives on the topic of digital innovation in the area of Cyber-Physical Systems (CPS). The analysis below focuses on these.

Digital twins, simulations (Challenge 1):

The Platform4CPS Roadmap, published in 2018, is a community roadmap reports and provides a comprehensive overview of preceding roadmaps. In regard to the challenge of digital twins and simulation technology, both were prominent themes in this report. In particular, the Platforms4CPS Roadmaps states that "new or improved **engineering approaches** are needed to manage and integrate increasingly complex systems with functionalities from multiple domains, including electrical, mechanical, physical engineering, computer science and communication. Increasingly this is being supported by the development of **'digital twins'** to analyse and monitor a CPS (Cyber-Physical system) or CPPS (Cyber-Physical Production Systems) at design and runtime."

In its overview of previous reports, the Platform4CPS Roadmap outlines the prominence of digital twins, and points out that this technology will "effect on updating or replacing constituent parts of a CPS can be analysed and tested in advance on the digital twin." In terms of recommendations, this roadmap designated that both "**CPS virtual engineering, modelling and simulation**" and "model-based systems engineering including agile, open plug-and-play CPS platforms" were both high research priorities. Lastly, on the top of model connectivity, the priority of "connectivity, computing, and seamless storage" was also considered an important research area.

The report also emphasises that "CPS/CPPS are **complex, often large and expensive** systems it is necessary that analyses can be performed before the concrete system is being built, i.e. at design time, by **simulating the system behaviour at model level**." Some challenges related to this are:

- Scale the current simulation and analysis methods and tools to cope with the systems size
- The need to integrate design methods from various engineering disciplines involved CPS
- Understanding the function and behaviour of standard or legacy components
- Supporting the full product life cycle

Overall, Platforms4CPS argues that "simulation and analyses are also important when the system is being deployed, to **monitor runtime operations**, detect potential mal-function or unanticipated context changes." Such systems are needed to be able to map the observed behaviour to the model level, including system requirements and safety cases, which allows for an easier understanding when a system deviates from its intended behaviour, and to identify and eliminate potential causes. "**digital twins**", or fully virtual copies of a CPS, allow for analysing deviating behaviour by replaying it on virtual systems. Furthermore, effects of updating or replacing constituent parts of a CPS can be analysed and tested in advance on the digital twin.

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AI, machine learning, big data (Challenge 2):

The Platforms4CPS roadmap also covers several of the major themes under Challenge 2, related to AI, machine learning, and big data. While the subtopics of 5G and object detection were not extensive discussed, the roadmap outlined the maturing technologies of self-monitoring systems and deep analysis data mining such as improvement trends that will continue to grow. One expected maturity is in the area of neural network technology, which is modelled after brain functions.

The Platforms4CPS roadmap also highlights that a vast amount of (real-time) information is becoming available. This is driving **data analytics**, data fusion, decision support and **machine learning**. Expert Systems are being revolutionised via the use of **AI**, e.g. **deep learning**, and centralised cloud-based systems are exploiting large amounts of data. In the coming years, much more technology is expected for **information extraction** from data and particularly **AI-enabled filtered information extraction**. Additionally, algorithms should provide **filtering against corrupt data** and advanced **situational awareness** and **collaborative decision-making** functionalities.

The Platforms4CPS roadmap structures its findings from surveying other roadmaps and placed them in a Technology and Research Radar structure consisting of 8 themes. It can be observed that two of these themes, 'Humans in the Loop/HMI (Human-Machine Interface)' and 'Autonomy and Robotics' are both closely related to the identified Challenge 2 from ECSEL SRA. In addition, two other subtopics under this theme emerge in the Platforms4CPS Roadmap. Artificial intelligence (AI) was thoroughly discussed as a key component of CPS systems, and it was recommended in the report that further research take place on how to create a 'trustable system' with public awareness about AI. Additionally, the subtopic of **edge computing** describes an important trend. The Platform4CPS roadmap suggest that the edge is becoming increasingly important to the EC, and that it may open up new business opportunities to move toward this process of localizing intelligence. The future foresees AI being exploited at the **edge** requiring specialised, low power hardware such as neuromorphic processors and in the longer-term quantum processors.

According to the roadmap, AI is also being exploited in Cognitive CPS, for example in systems that can analyse their own behaviour and self-optimise their processes according to changing requirements, observations, or context. **Trustable decision making, mission and action planning** will be key for reasoning through **predictive and cognitive CPS**. **Ethics** plays a pivotal role, especially as trust of the general public and acceptance of the systems is of utmost importance.

Furthermore, the roadmap discussed that autonomous systems will evolve from self-healing, self-learning to self-reconfiguration and **full-autonomous decision-making** as well as from machine learning, pattern-recognition, and data-fusion towards algorithms to extract filtered information. Interactions with humans are being changed via semi-integration of **cobots** and user interface adaptability and will steer towards **AI-enabled assistants**.

As a recommendation to meet Challenge 2, the Platforms4CPS roadmap states that "Europe should enhance activities to master "trustworthy CPS for AI (artificial intelligence) enabled autonomous systems with humans in the loop." It further recommends that more research priorities be made under the topics of the following:

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- Autonomous systems, cognitive systems, artificial intelligence
- Human machine awareness, HMI
- Trustable AI-enabled autonomous CPS
- Integration, interoperability, flexibility, and reconfiguration

Condition monitoring, decision making (Challenge 3)

In regard to Challenge 3, the Platforms4CPS report also covers many subtopics related to conditional monitoring and decision-making involved CPS technology. Major themes discussed overall in the report consisted of **big data** and use of **real-time analytics** to support **decision making** in terms of manufacturing. However, on the non-technical side, it also specified that other reports surveyed made referred to the **business models** for CPS, and how collaboration between all stakeholders is important for balanced decision making in the sector overall.

According to the report, significant developments related to condition monitoring and self-maintenance are expected in the near future. This will result from advances in **self-diagnosis** capabilities, **real-time monitoring** and **predictive maintenance** and **self-healing**. The **digital twin, supplemented by embedded AI**, will play an important role, where the system maintains a virtual model of itself and the environment. It is believed that system self-monitoring and **deep analysis data mining** would be maturing, supported by **neural network technology**. Analyses of behaviours/problems/solutions would be communicated back to the manufacturing facility then applied in subsequent updates.

Platforms4CPS states that the future in Europe is moving rapidly towards a **data-driven economy**, and it pointed out that some barriers standing in the way of that progress consist of unclear semantics and descriptive language, as well as missing open data. From its survey of related roadmaps, the Platforms4CPS report expects that achieves will be made to meet Challenge 3, as named by ECSEL SRA. These will consist of "**visualisation, virtualisation, situational awareness and decision support**" as well as "decision structures and system architectures" that can support future work with big data analytics.

Tools and recommendations made in the report related to this challenge are "integration, interoperability, standards, platforms, reference architectures." Additionally, Platforms4CPS specifies that research priorities be made in "big data awareness", "big data-based decision making, "**sensor data fusion**" and "**efficient handling of big data**."

Furthermore, there will be **self-reconfigurable modular robots** being able to adapt their physical structure and behaviours to different environments including new untested conditions. This links also to **self-learning** and **analysis of user behaviours** – the systems are out there doing different tasks and able to learn while they are carrying their actions. Depending on where operation takes place, there are safety concerns because if the machine is learning on the job it can introduce unforeseen behaviours. Especially in the case of **cobots**, interacting closely with humans, it may mean learning would be required to take place in test environments. It is also believed we shall be seeing **new types of sensors and actuators** bringing new functionalities to systems.

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Digital platforms (Challenge 4):

On the topic of Digital Platforms, the Platforms4CPS document states this as a major theme in relation to CPS. In particular, it references several time the importance of open source systems, and it set an expectation from its survey of other reports that ‘**openness**’ (open data, architectures, platforms, open innovation, open environments, open ecosystems) is an important theme in Europe as it marches towards Industry 4.0. The report lists important research priorities as “integration of platforms,” and highlights the important of using digital platforms as a means of building ecosystems needed to establish new business models.

Currently, there is a very **fragmented landscape** of vertical and horizontal as well as open and closed platforms. This is expected to move more and more towards composable, plug-and-play components, federated towards increasingly decentralised dynamic platform compositions. The digital platforms of the future are foreseen to become trusted multi-sided CPS marketplaces within business ecosystems. The future depends on the use and exploitation of data and here there is a need for openness, with open data and **federated agile open platforms** to enable open innovation. The importance of interoperability (technical, syntactic, semantic, organisational) of **CPS architectures and platforms** whether proprietary, open source, vertical, horizontal or business to business will increase. Looking further in the future, it is expected that dynamic islands of platforms will come together temporarily to provide services with a trend for increased decentralisation towards the **edge**, **autonomy**, orchestration, more connectivity, and agnostic connectivity with respect to vendors and protocols. Moreover, **ledger-based platforms** will gain in importance.

In conclusion, there are a number of *trends*, such as **increased decentralisation, autonomy, orchestration, more connectivity, and agnostic connectivity** with respect to the vendor and protocols. It will be necessary to change platforms in response to **AI** and, in particular, there will be a move from centralised AI in the cloud to decentralised AI at the edge. Therefore, there is a need for **platforms that support AI at the edge**, **neuromorphic processors,** and in the longer-term, **quantum processors**.

Cross-cutting aspects present in ECSEL:

The main **technological barriers** highlighted in the Platforms4CPS Community Roadmap are a lack of **interoperability** between components as well as systems, missing **standards** and resulting difficulties with the **integration** of legacy systems. Challenges regarding safety, stability, **dependability** and resilience of ‘always on’ and emerging CPS pose high demands to engineering and still present a bottleneck to wider exploitation. Mastering the ever-growing **complexity**, terminology, semantics and achieving cost-efficient verification, validation and testing is a big challenge. Moreover, **CPS safety, security,** trustworthiness, compliance and transparency are main priorities in relation to CPS deployment and have to be implemented by design and co-engineered. Frameworks for legislation, certification, and cybersecurity are needed. The move towards **autonomous systems** raises many new questions, which will have to be answered not only by technological advances, but also by society. Systems that people can **trust** will be crucial for the success of future CPSs, especially those, whom we will allow to take decisions for us. Ensuring trust and considering ethics is of utmost importance as well as **maintaining sovereignty** in key value chains.

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Platforrms4CPS recommendations for research priorities for the above cross-cutting themes include:

- **Integration, interoperability, flexibility, reconfiguration** including semantic interoperability and models, openness and open standards, automatic (re-)configuration and plug-and-play
- **Safety, robustness, resilience, and dependability** including fault detection and mitigation for secure real-time and mixed-criticality systems, risk-based testing of autonomous/intelligent systems, fail-safe operation of intelligent/autonomous systems
- **Cybersecurity, privacy, trust** including blockchain, distributed ledgers digital identities, trusted and adaptive security architecture, co-engineered safety and security
- **Connectivity, computing and storage** seamless connectivity, hyper convergence and wireless intelligence, edge computing and edge cloud interactions, intelligent edge devices, new disruptive technologies including quantum technologies, cognitive computing, neuromorphic computing, brain inspired computing

Innovation accelerators needed for successful implementation are multi-disciplinarily and **cross-fertilising** approaches as well as coordinated collaboration to **reduce fragmentation** across the EU. T-shape education, lifelong learning and **reskilling** and CPS enabled **business models** and services are very important. Demonstrators and **living lab** are essential to alleviate concerns and regulatory, legal and ethical issues to ensure a reliable framework. Not only are societal dialogue and awareness raising seen as crucial elements of future CPS success, but also real **user acceptance** and trust are just as important. Further points included to focus EC incentives on **open approaches** such as open data, open platform building, open innovations as well as open source solutions.

2.3.5.3 Emerging trends and potential gap with the ECSEL SRA

Emerging Trends / Technological Developments:

Regarding the technology trends and new/emerging themes **autonomous systems** become very prominent in connection with **Artificial Intelligence** and **trust**. According to Platforms4CPS there is a need for understandable, accountable autonomous systems, which act ethical and where liability questions have been solved. Next to data-driven CPS basing their decisions on analytics by deep learning and new AI methods, neurocognitive systems and brain-inspired computing will be challenges ahead. Moreover, handheld devices will partly be replaced by wearables or even implantable devices. The interaction and **collaboration between CPS and humans** will be intensified (intuitive, assisting systems, humanoid robots), the human becoming a functional part of the system, towards **the fusion between CPS and the human** enabled brain-computer interfaces.

New or improved (virtual) **CPS engineering** approaches to manage the more and more **complex systems** including the **human as a part**, but also **co-engineered safety, security and ethics** as a part of it are discussed intensively. Future system will have to predict and adapt to human needs, preferences and capabilities. Research and development will have to cross the silos, regarding disciplines but also application domains. Cross fertilisation (biology and computing, ethics and engineering) will be key.

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In relation to **digital platforms**, there are a number of *trends*, such as **increased decentralisation, autonomy, orchestration, more connectivity, and agnostic connectivity** with respect to the vendor and protocols. It will be necessary to change platforms in response to **AI** and, in particular, there will be a move from centralised AI in the cloud to decentralised AI at the edge. Therefore, there is a need for **platforms that support AI at the edge**, **neuromorphic processors,** and in the longer-term, **quantum processors**.

Innovation related:

Next to research and technology priorities, many CPS roadmaps identify 'non-technological' priorities that can act as innovation accelerators or enablers for market adoption. The roadmaps specifically mentioned the following groups of innovation accelerators:

- **Overcoming fragmentation** in Europe through coordinated efforts
- **Enhancing collaboration** across domains and value chains and with related projects
- Building and sustaining a supportive and stimulating **innovation ecosystem**
- Elaborating **business models**
- Creating an **open business environment** with open data, architectures, platforms and standards as well as open innovation and open environments
- Facilitating **access to SMEs** and **start-ups**
- Providing research and service **infrastructure** as well as testing facilities and **demonstration**
- Clarifying issues on **law** and **regulation**, Single Digital Market
- Stimulating cross-disciplinary **education** and reskilling, educate society
- Raising societal awareness, **stimulate dialogue**, and enhance **user-acceptance**

In terms of improving **market adoption**, there were a number of common requirements from different application domains. These include:

- Enhancing integration, standardisation, interoperability, modularity and flexibility of solutions
- Providing easy to use and easy to understand plug-and-play platforms based on shared standards
- Ensuring sustainability of the provided technology (upgradable, adaptable, flexible, in the context of the long-term oriented equipment investments)
- Fostering new business models and stimulating a culture of innovation/entrepreneurship
- Building up an innovation ecosystem and facilitate the integration of SMEs and innovators
- Implementing of open solutions, avoid vendor lock (change mind-set of relevant players)
- Reducing risk and implementation costs by providing demonstration, testing facilities, success stories and best practices
- Addressing safety, security and privacy issues as well as IP protection
- Elaborating of regulatory and legal frameworks for CPS and implementations in different domains
- Enhancing collaboration and reduce fragmentation of efforts, to match supply and demand
- Enhancing training and education as well as reskilling possibilities and attracting talent to the EU
- Raising awareness and interest in CPS and foster societal dialogue

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Additionally, two related “Threats” named by the report consists of “**Addictive** systems and society's enhanced independence” and consequential “increasing **vulnerability**.” The report also mentions that aspects of “trust” as well as maintaining sovereignty in key value chains are important objectives to be reached. In terms of extending research priorities, the Platforms4CPS report states that “research activities have to be **embedded into a suitable innovation environment** and **answering real societal needs**.”

Possible Gaps:

- **Trustable AI-enabled autonomous CPS**, cognitive systems and situation awareness, diagnostics, prognostics and large-scale data analytics/decision support and explainable AI
- **Human-in-the-loop**, human as part of the system and HMI including **intuitive systems**, wearable and implantable systems, virtual and augmented reality as well as human machine collaboration and collaborative decision making
- **Education and skilling,** T-shape education, re-skilling, up-skilling, life-long learning and future job profiles
- **Business related,** Business models, (flexible) open business environment, market adoption, technology modularity, interoperability and sustainability
- **Manufacturing ecosystems,** agile networks, open platforms, demonstration, society and ethics

2.3.6 Big data

The material used in this section is collected from Big Data European Big Data Value Strategic Research and Innovation Agenda (October 2017) and “Big data challenges in smart manufacturing: A discussion paper on big data challenges for BDVA and EFFRA Research & Innovation roadmaps alignment” (March 2018).

The discussion paper is characterised as follows: The aim of this discussion paper is to create consensus in the BDVA and EFFRA communities about the need for a win-win symbiotic cooperation between the two Big Data and Manufacturing sides of the Digitising industry coin, in order to strategically align respective reference architectures and technological roadmaps as well as to identify at a more implementation level common challenges for Big Data technologies adoption by Manufacturing Industry, materializing the coin metaphor.

2.3.6.1 Summary

The Strategic Research and Innovation Agenda (SRIA) defines the overall goals, main technical and non-technical priorities, and a research and innovation roadmap for the European Public Private Partnership (PPP) on Big Data Value. The BDVA Big Data Value Reference Model summarises core BDVA, collaboration activities and data types.

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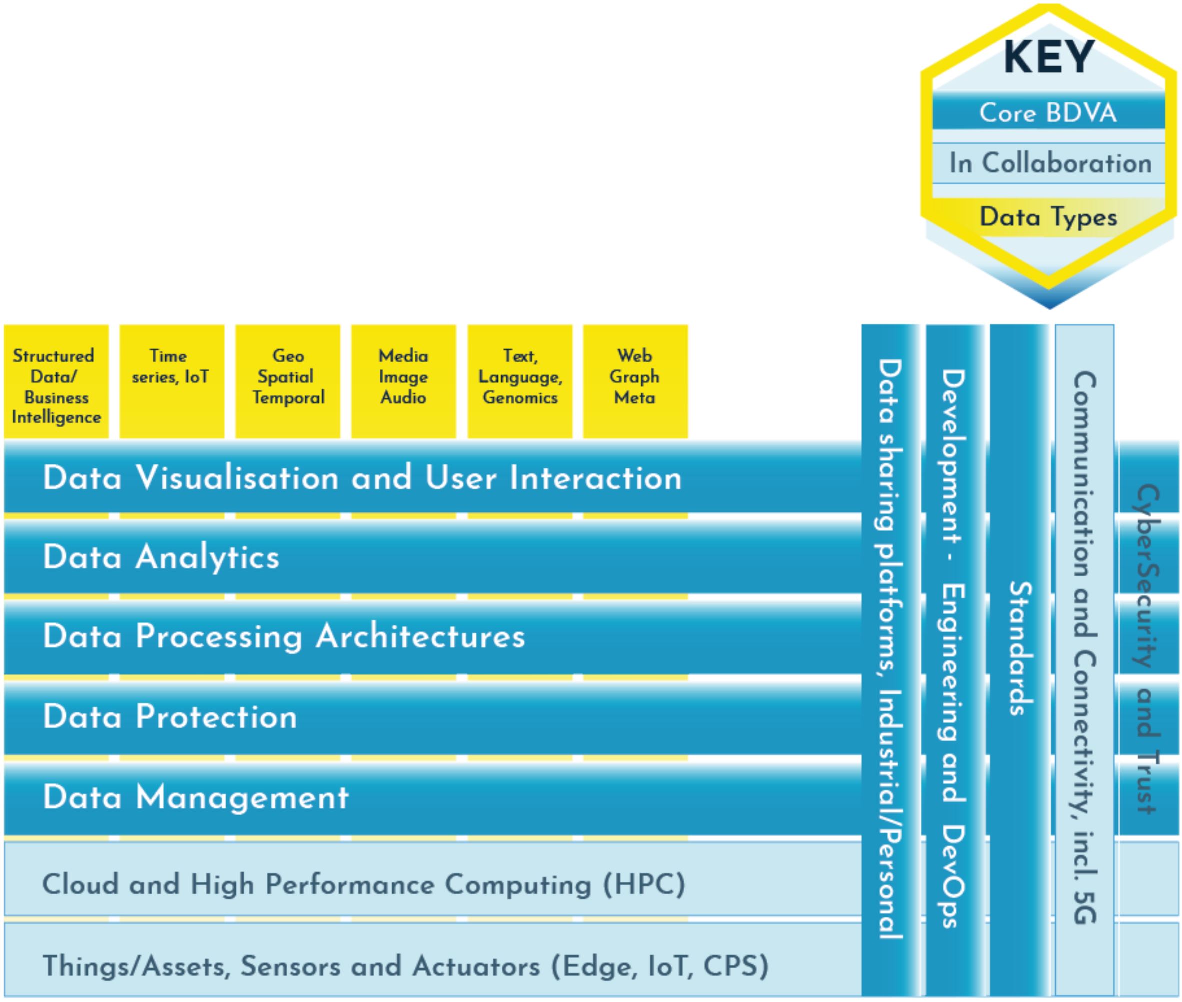

Figure 10: Big Data Value Reference Model]

Technical priorities can be further summarised:

1. **Data Visualization and User Interaction**: Advanced visualization approaches for improved user experience. This technical priority is addressing the need for advanced means for visualization and user interaction capable to handle the continuously increasing complexity and size of data to support the user in exploring and understanding effectively Big Data.

2. **Data Analytics**: Data analytics to improve data understanding, deep learning, and meaningfulness of data. The Data Analytics technical priority aims to progress data analytics technologies for Big Data in order to develop capabilities to turn Big Data into value, but also to make those approaches accessible to the wider public.

3. **Data Processing Architectures**: Optimized and scalable architectures for analytics of both data-at-rest and data-in- motion with low latency delivering real-time analytics. This technical priority is motivated by fast development and adoption of Internet of Things (IoT) technologies that is one of the key drivers of the Big Data phenomenon with the need for processing immense amounts of sensor data streams.

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4. **Data Protection**: Privacy and anonymization mechanisms to facilitate data protection. This is related to data management and processing as it is a strong link here, but it can also be associated with the area of CyberSecurity.

5. **Data Management**: Principles and techniques for data management. This technical priority is motivated by the data explosion that is mainly triggered by the increasing amount of data sources (e.g. sensors and social data) and their complexity in structure.

In the BDVA Valencia Summit (November 2016), EFFRA detailed the seven main Research Headlines concerned with the Big Data and Industrial Analytics domains: (ECSEL SRA digital industry related bolded)

HL16 Digital Factory Modelling and Simulation, including Real–Digital World Synchronisation (the Digital Twin);

HL17 Multiple Source (Big) Data Mining and Real Time Advanced Analytics in Product and Production Lifecycle Ecosystems;

HL19 Digitisation of the Supply Chain – Manage complex customer-driven value networks;

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

HL25 Digital Platforms Interoperability and Open Standards development;

HL26 Security, Privacy and Liability – Cybersecurity and Industrial Safety;

HL28 European Circular Economy Open Platform

EFFRA has defined scenarios aiming at representing all the different features of a SMI in Europe:

1. **Smart Factory** grand scenario, where data is generated inside production lines and analytics is needed for safety, optimization and diagnosis of the plant as well as of the blue-collar workers. Key topics in this scenario are: Factory Automation; Machinery & Robots; Internal Logistics; Smart Workplaces; Cyber Physical Production Systems (as in the original German Industrie 4.0 concept). In this domain, Industrial Analytics could support advanced applications including but not limited to e.g. Production Lines design and ramp-up; Production Monitoring and Control; Production Planning and Scheduling; CPS modelling and simulation; Energy/Waste Consumption Optimization; Diagnosis and Predictive Maintenance; Zero Defect Manufacturing; Workplace Human-Machine interaction; Workers Training and Augmented Reality.
2. **Smart Supply Chain** grand scenario, where data is generated by ecosystems of suppliers, providers, distributors, retailers and analytics is needed for value chain integration and white-collar workers collaboration. Key topics in this scenario are: Trends and Sentiment analysis; Open Innovation and Living Labs; Supply and Distribution Chain Optimisation; Inbound and Outbound Logistics optimization; Closed loop Manufacturing synchronization; Industrial Symbiosis; Co-operative Working Environments for engineers and managers; Retail and Consumer experience monitoring; product-service cross-domain ecosystems.

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3. **Smart Product Lifecycle** grand scenario, where data is generated by the product-service itself along its lifecycle in a Circular Economy perspective and analytics is needed for product operations monitoring and control. Key topics in this scenario are: new Product-Service ideation and design; Closed Loop Engineering; Product Operations Monitoring, Product Preventive and Predictive Maintenance; De- Re- Manufacturing and Re-cycling; As-designed As-built As-maintained models; Sharing and Service economy Business Models for Product Service Systems.

These scenarios are developed as pathways within a specific scope of digitisation, referred to as 'personas':

1. **Hyperconnected Factories**: (Digital Platforms for) networked enterprises in complex, dynamic supply chains and value networks, where data flows across different administration domains
2. **Autonomous Factories**: (Digital Platforms for) optimised and sustainable manufacturing including advanced human-in-the-loop workspaces, where real time data streams need to be processed
3. **Collaborative Product-Service Factories**: (Digital Platforms for) data-driven product-service engineering in knowledge intensive factories, where various combinations of product- and service-data need to be integrated in order to offer innovative solutions and business models

Following figure shows how technology focus varies in different scenarios:

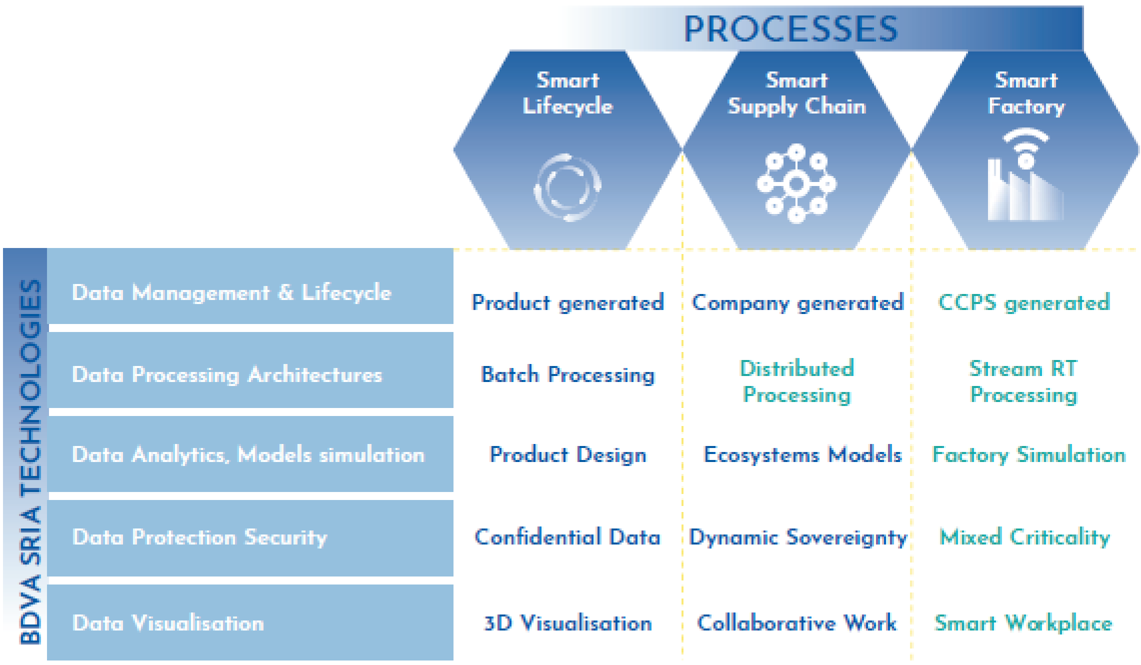

Figure 11: BDVA technologies in different scenarios

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2.3.6.2 Analysis

The analysis was made comparing both ECS SRA 2019 and BDVA SRIA and related paper on BDVA in smart manufacturing industry.

Digital industry major challenges

Major challenge 1: Developing digital twins, simulation models for the evaluation of industrial assets at all factory levels and over system or product lifecycles

- Digital twins are addressed in priority area 'Data Analytics' in HPDA reference applications´
- Simulations are addressed in priority area 'Data Processing Architectures' challenges in "Novel architectures for enabling new types of big data workloads (hybrid Big Data and HPC architecture)"
- Simulations are addressed in priority area 'Data Analytics' challenges in "High Performance Data Analytics (HPDA)"

Major challenge 2: Implementing AI and machine learning to detect anomalies or similarities and to optimise parameters

- This challenge is directly related to BDVA mission being … "sustaining Europe's leadership in the fields of Big Data Value creation and Artificial Intelligence."
- BDVA SRIA sees big data and cyber security as complementary to each other and this challenge is part of the means how to improve cyber security
- AI and machine learning are addressed in priority area 'Data Analytics' in challenge "Data analytics and Artificial Intelligence". The challenge is how the use of the progress in efficient and reliable data analytics processes is made visible to advanced business applications.
- Simplified end-user mechanisms are addressed in priority area 'Data visualisation and user interaction' in "New paradigms for visual data exploration, discovery and querying"
- BDVA SRIA identifies lack of standards as one obstacle in machine learning and AI

Major challenge 3: Generalising condition monitoring, to pre-damage warning on-line decision-making support

- Manufacturing and production, namely efficiency gains and predictive maintenance are seen as one of the impact areas for analysis techniques.
- BDVA SRIA sees 5G PPP as close collaboration partner collecting big data from real-time networks.

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- Real-time data analytics are addressed in priority area 'Data Management' challenges in "Data lifecycle management and data governance"
- Predictive systems (such as recommendation engines) are addressed in priority area 'Data Processing Architectures' challenges in "Scalability"
- Predictive and prescriptive analysis is a challenge in priority area 'Data Analytics'
- Event and pattern discovery is one of the outcomes in priority area 'Data Analytics' that includes discovery and prediction of rare real-time events

Major challenge 4: Developing digital platforms, application development frameworks that integrate sensors and systems

- Industrial data sharing platform is defined in the BDVA SRIA as a concept solution, covering all BDVA SRIA technologies. "The IDP conceptual solution is oriented towards proprietary (or closed) data, and its realisation should guarantee a trusted, secure environment within which participants can safely, and within a clear legal framework, monetise and exchange their data assets. The establishment of a trusted data-sharing environment will have a substantial impact on the data economy by incentivising the marketing and sharing of proprietary data assets (currently widely considered by the private sector as out of bounds) through guarantees for fair and safe financial compensations set out in black-and-white legal terms and obligations for both data owners and users."
- Data lifecycle management and data governance is a one challenge in 'Data management' priority area
- Real-time architectures for data-in-motion is one outcome of priority area 'Data Processing Architectures'
- Collaborative 3D and cross-platform data visualisation frameworks are an outcome in priority area 'Data visualisation and user interaction'

Cross-cutting aspects in BDVA SRIA

In addition to priority areas listed in BDVA SRIA, SRIA also identifies several areas that are cross-cutting, namely:

Technical aspects: Big data standardization

The SRIA notes that standardisation applies both to the technology and the data and sees a lack of standards as a major obstacle for big data. Standardisation is difficult since big data is very varied topic. However, BDVA SRIA especially sees potential in data exchange and data interoperability standards.

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Technical aspects: Engineering and DevOps for big data

BDVA SRIA notes that continuous development and operations (devops) of big data value systems not yet mature with proven technologies. Main challenges are:

- Big data value engineering, especially with unified systems perspective that integrate data management, analytics and data protection.
- Quality assurance, proven methods in software engineering must be extended to big data value, and means to tackle velocity must be found.
- Multiple dimensions of big data value, real time-processing and analytics that take into consideration data veracity and variety.

Non-technical aspects: Skills development

BDVA SRIA sees skills as one of the key issues in order to leverage potential of big data value, including systematic analysis of needs and spreading out best practices through education and training.

The SRIA also states that data science engineering approach is not enough due to the variety of skills and technologies needed. Therefore, it suggests experience-driven approach to education, instead of knowledge-based approach, in order to better match the needs of data-oriented organisations.

Non-technical aspects: Ecosystems and business models

The SRIA identifies three key ways to big data value creation: optimising and improving core business, selling data services and creating entirely new business models and business development. Sustainable business models and value ecosystems are a key challenges, following stakeholders can be identified:

- User enterprises (using big data in their operations)
- Data generators and providers
- Technology providers
- Service providers

Non-technical aspects: Policy and regulation

BDVA states that there is currently no mandate nor competence to be involved directly in policy making or regulatory frameworks.

Non-technical aspects: Social perceptions and societal implications

There are several societal challenges identified by BDVA that include:

- How to increase trust in big data innovations
- How to include privacy-by-design principle

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- How to develop collective awareness of big data innovations and how to demonstrate social benefits
- How to identify ethical issues

EFFRA/BDVA challenges paper analysis wrt. ECSEL SRIA 2019

"Big data challenges in smart manufacturing: A discussion paper on big data challenges for BDVA and EFFRA Research & Innovation roadmaps alignment" identifies several big data related challenges in three EFFRA smart manufacturing industry scenarios, namely Smart Factory, Smart Supply Chain and Smart Product Lifecycle scenario.

Following table compares the four major challenges presented in ECS SRA 2019 digital industry section and challenges identified in EFFRA/BDVA challenge analysis.

Addressed = The EFFRA/BDVA challenge is addressed in digital industry major challenge (MC)

Related = could be related but it is not addressed.

Empty = no identified correlation. Note that in some cases digital industry chapter addresses some topics although they are not directly addressed in major challenges section.

Smart Factory Scenario

	ECS MC 1: digital twins, simulations	ECS MC 2: AI and machine learning	ECS MC 3: condition monitoring	ECS MC 4: digital platforms
Data management & Lifecycle Challenges				
a) SFI, CPS data sources integration	Addressed		Related	Addressed
b) Automatic systems, semantic interoperability	Addressed			Addressed
c) Smart factory data annotation		Related		
d) Smart factory unstructured,				

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semi-structured and missing data				
e) Industrial IOT data availability		Related	Addressed	Addressed

	ECS MC 1: digital twins, simulations	ECS MC 2: AI and machine learning	ECS MC 3: condition monitoring	ECS MC 4: digital platforms
Data processing architecture challenges				
a) On-premise vs Cloud smart factory architectures		Addressed		Addressed
b) Hybrid clouds and edge automation architectures		Addressed		Addressed
c) Smart factory data in motion, data at rest integration			Related	Addressed

	ECS MC 1: digital twins, simulations	ECS MC 2: AI and machine learning	ECS MC 3: condition monitoring	ECS MC 4: digital platforms
Data analytics challenges				
a) Prescriptive analysis in			Related	

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industrial plants				
b) Machine and deep learning in smart factory		Addressed	Addressed	
c) Analytics for data-human interaction of factory models				
d) Analytics-based decision-support in manufacturing operations management			Addressed	
e) Embedded analytics	Related		Addressed	
f) Analytics-oriented manufacturing simulation model	Addressed			
g) Digital twin for analytics	Addressed			

	ECS MC 1: digital twins, simulations	ECS MC 2: AI and machine learning	ECS MC 3: condition monitoring	ECS MC 4: digital platforms
Data protection & security challenges				
a) Sensitive data privacy in				

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future workspaces				
b) Protection about cyber-attacks in smart factory		Related		Addressed
c) Access control & data integrity in smart factory critical infrastructures		Related		Related
d) Selective anonymization in smart workspaces				

	ECS MC 1: digital twins, simulations	ECS MC 2: AI and machine learning	ECS MC 3: condition monitoring	ECS MC 4: digital platforms
<u>Data visualization challenges</u>				
a) Context-aware visualization in smart workplaces	Addressed			
b) Visual analytics for smart factory decision-makers	Addressed	Related	Addressed	
c) Smart factory natural language		Addressed		

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interaction interfaces				
d) Cross-domain and data exploration	Addressed	Related		
e) Simulation and training environments	Addressed			

Smart Product lifecycle scenario

	ECS MC 1: digital twins, simulations	ECS MC 2: AI and machine learning	ECS MC 3: condition monitoring	ECS MC 4: digital platforms
Data management & Lifecycle Challenges				
a) Product design interoperability	Addressed			
b) Product operations data cleaning and curation				Addressed
c) Product lifecycle data management	Addressed			Addressed
d) Provider-user data integration				

	ECS MC 1: digital twins, simulations	ECS MC 2: AI and machine learning	ECS MC 3: condition monitoring	ECS MC 4: digital platforms

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Data processing architecture challenges				
a) Data at rest smart product pre-production	Related			
b) Data in motion for smart product post-production				Addressed

	ECS MC 1: digital twins, simulations	ECS MC 2: AI and machine learning	ECS MC 3: condition monitoring	ECS MC 4: digital platforms
Data analytics challenges				
a) Pre-processing product data and deep learning				Related
b) Real time analytics in smart product operations				
c) Complex products digital twins alignment	Addressed			

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d) Product-service systems modelling				

	ECS MC 1: digital twins, simulations	ECS MC 2: AI and machine learning	ECS MC 3: condition monitoring	ECS MC 4: digital platforms
Data protection & security challenges				
a) Data confidentiality and IPR in smart products pre-production				
b) Privacy preservation in smart products post-production and operations				

	ECS MC 1: digital twins, simulations	ECS MC 2: AI and machine learning	ECS MC 3: condition monitoring	ECS MC 4: digital platforms
Data visualization challenges				
a) 3D visualization of complex smart products	Addressed			

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b) VR/AR in maintenance and operations of complex smart products		Addressed		
c) Update smart products visualization at runtime				
d) Highly configurable smart products visualization for the user				
e) Product data visualization by the user	Related			

Smart Supply Chain Scenario

Supply chain is only shortly addressed in major challenge 4 section and therefore it is not necessary to present the whole table as in other EFFRA scenarios.

2.3.6.3 Emerging trends

IDC's European Vertical Markets survey conducted at the end of 2017 found that approximately **32% of interviewed manufacturers** already used Big Data and Analytics solutions, with another 7% planning to introduce them within the following year. Big Data initiatives are gradually moving beyond the IT department and reaching business intelligence/analysts across lines of business. The demand is especially driven by the analysis of operational data and factory automation.

IDC sees a majority of large manufacturers engaged in integrating information from myriad sources with predictive and prescriptive analytics, machine learning, and cognitive computing to drive continuous improvement in how data value is developed and realized throughout the value chain. Monetization of data from and about products, customers, and markets is becoming embedded into the enterprise's business strategy and is about to become a significant source of revenue and competitive strength. The sectors that are currently benefitting more from this trend are **automotive**

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and industrial machinery. Many market leaders in these sectors are based in Western Europe, so the region is in a particularly good position to profit from this trend. [2]

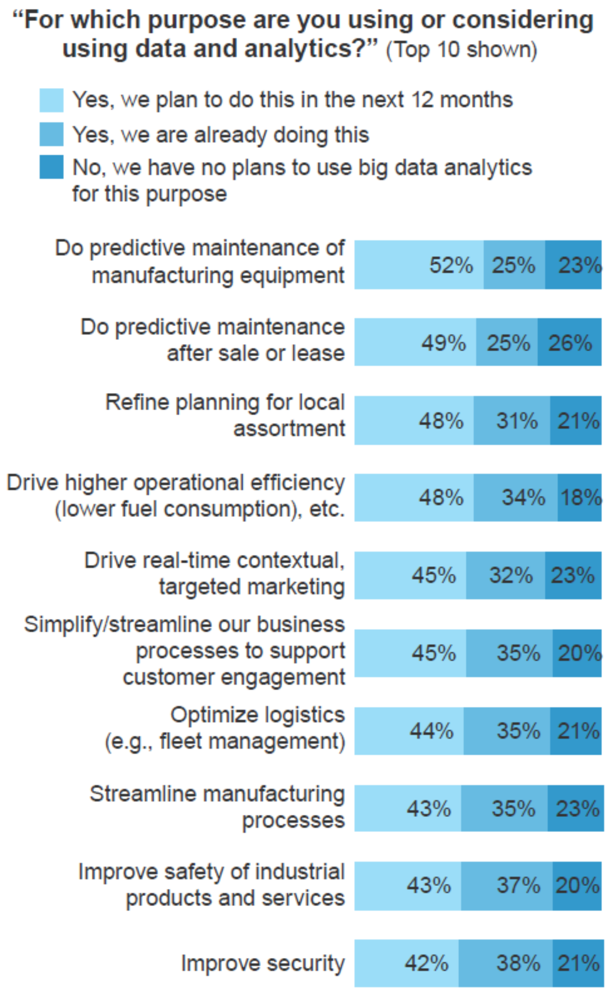

Figure 12: Data analytics use cases in manufacturing [3]

IDC estimates that by 2020, 80% of large manufacturers will update their operations and operating models with IoT and analytics-based situational awareness to mitigate risk and speed time to market. [4]

[2] Manufacturing IT Strategies: Findings from the IDC European Vertical Markets Survey", 2016 - https://www.idc.com/ getdoc.jsp?containerId=EMEA41421217

[3] Manufacturing IT Strategies: Findings from the IDC European Vertical Markets Survey", 2016 - https://www.idc.com/ getdoc.jsp?containerId=EMEA41421217

[4] Manufacturing IT Strategies: Findings from the IDC European Vertical Markets Survey", 2016 - https://www.idc.com/ getdoc.jsp?containerId=EMEA41421217

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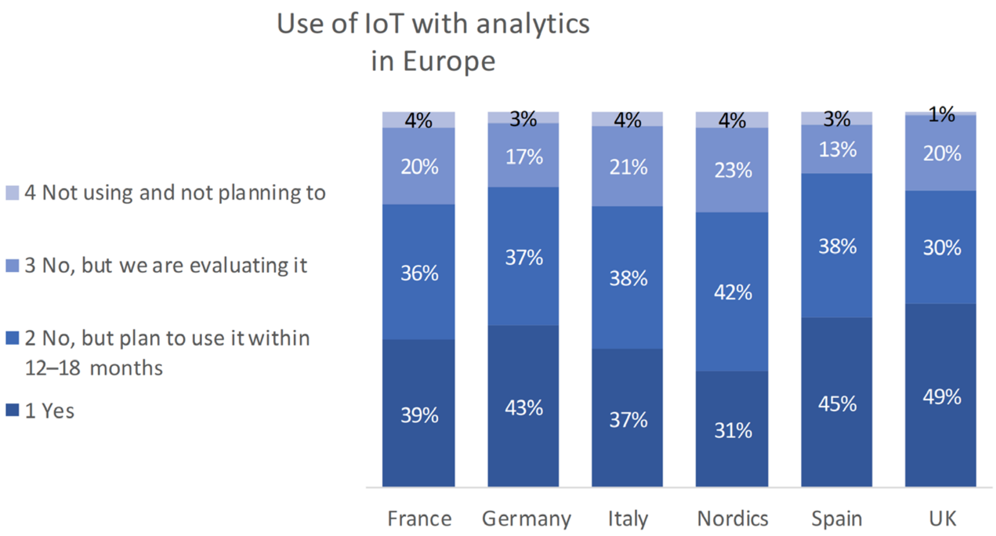

Figure 13: Use of Big Data and Analytics by Country (% of enterprise respondents) [5]

BDVA SRIA identifies following topics on managing digital transformation of society and economy:

1. Digital skills
2. Start-ups and digitalisation of all industry and service sectors, specially focusing on ICT standards
3. Digital innovation for modernising public services
4. Stepping up investments in digital technologies and infrastructure

In this paradigm-shift towards data-driven socio-economic model, data is in key role. Especially critical is the trust issue, trust to data-driven decision-making and trust to AI platforms.

Data-sharing and trading platforms are seen as enablers of data economy. Industrial data platforms are touted as potential catalysts for advancing data economy. Trusted data-sharing environments would increase proprietary data potential. Personal data platforms are seen as a possible solution to that gives data subjects and data owners control over how their data is used.

[5] Manufacturing IT Strategies: Findings from the IDC European Vertical Markets Survey", 2016 - https://www.idc.com/ getdoc.jsp?containerId=EMEA41421217

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2.3.7 HiPEAC Vision

2.3.7.1 Summary

The HiPEAC Vision 2019 discovers new trends of ICT and is structured into two main chapters: Key Messages and Rational. The first chapter presents the four key messages to foster ICT in Europe. The rationale part of the roadmap details the various elements that contributed to forging the recommendations through 6 main pillars (see Figure 14). This chapter starts by exploring the current situation in various aspects of business, and the implications of this. The second section analyses few aspects, which are required for an acceptable solution. After that, the roadmap explores the current silicon-based CMOS mainstream technology, its limitations and potential alternative approaches to keep improving systems. In addition, section 4 of the roadmap identifies current approaches and their limitations, before explaining where new solutions are required, followed by section 5 which is focused on the impact of ICT technology and society. Finally, the last section provides a SWOT analysis of the strengths, weaknesses, opportunities and treats of European ICT.

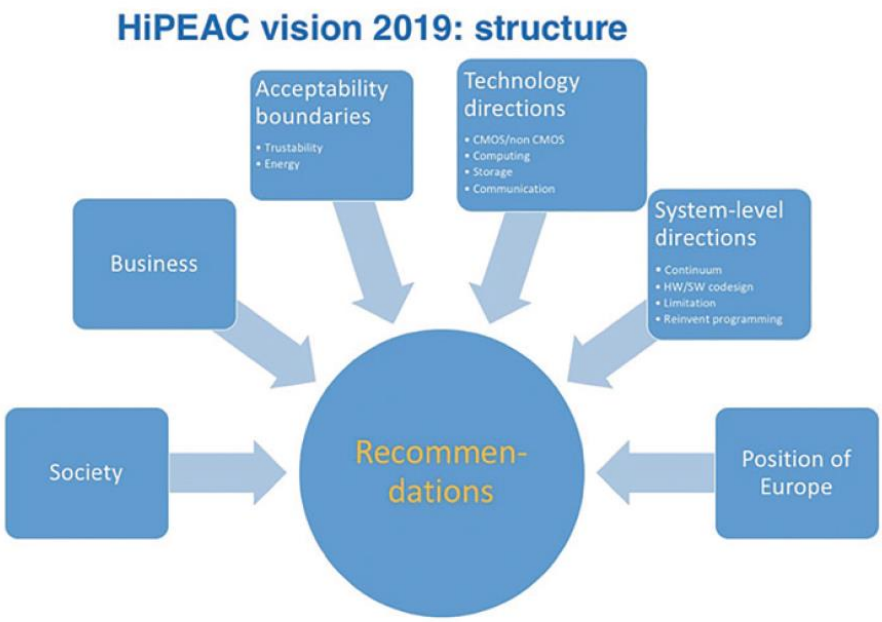

Figure 14: **Structure of the HiPEAC Vision 2019**

4 key findings described within Chapter 1 in the following areas:

- **Efficiency** - needs to be improved in all its aspects
- **Credibility, Security, Safety and Acceptability** - still a major challenge for ensuring the success of ICT systems
- **The position of Europe** - Europe has to keep its place in ICT, especially in the domain of CPS, edge or embedded systems
- **Society** - societal impact of ICT should be considered

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Regarding the Rational chapter the document analyses six focus areas and several subtopics in terms of the future development on ICT in Europe:

- **Business Dimensions** - business trends, business models, business domains and opportunities
- **Requirements for Acceptability** - trustable computer, energy challenge
- **Technology Directions** - emerging technologies, architecture heterogeneity, accelerators and in-memory computing, communication and network trends, storage trends, computational models
- **System-Level Directions** - continuum of computing, limitation of traditional programming, reinvent programming, smart design tools, software roadmap
- **Societal Dimension** - impact of computing technology on society and people, future job market and education, computing technology and future of Europe and planet earth, need for digital ethics
- **Position of Europe in the World** - SWOT analysis

2.3.7.2 Analysis

Digital twins, simulations (Challenge 1)

The HiPEAC Vision 2030 document contains much discussion in regard to Challenge 1 related to digital twins and simulations, as identified by ECSEL. On the topic of **digital twins**, the report states that this technology is especially useful for **prototyping, testing, and diagnostics,** where they can be used to **direct actions, settings and modifications** with their physical twin in the real world, and reduces the risk of unknowns, costs, and improves effectiveness of the product. HiPEAC also noted that software plays an important role in making digital twin technology usable in the manufacturing industry, and is a **compilation of simulation tools that include AR, VR, 3D modelling, and big data analysis**. However, the HiPEAC report advocates that in the future, "software should be written by software, not by programmers," since humans may not have the capacity to develop "correct, efficient, and secure code for new-generation heterogeneous computer platforms." In making this shift, the HiPEAC report asserts that this will be more viable for lead time and cost, and that this type of integrated software design should be an investment priority for Europe.

The HiPEAC roadmap also includes a comprehensive overview of **VR, AR, and MR** industry trends and products available on the market from the world's biggest tech companies, consisting of GAFAM (Google, Apple, Facebook, Amazon, Microsoft) and BATX (Baidu, Alibaba, Tencent, Xiaomi). Many of these consist of consumer entertainment products, but the report also includes an in-depth discussion on other high-tech simulation technologies in the field of neuromorphic computing (modelling how the brain works) and how these simulations are an enabler for possible important scientific discoveries.

The HiPEAC roadmap includes a very technical discussion on various computing models. But most importantly, it advocates that the development of new, innovative architectures for these models can be efficiently applied to specific applications that could lead to general performance increase and improvement.

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AI, machine learning, big data (Challenge 2)

On the second challenge identified by the ECSEL SRA report, related to AI, machine learning, and big data, the HiPEAC vision offers several insights. The report includes an extensive discussion about many **facets of AI**, and discusses several important points related to the high expectations for the future of AI and how it will **impact society**. One of HiPEAC's main recommendations in their 2019 report is that Europe needs to "**Accelerate, Specialize and Automate**" in order to embrace the future of AI. Overall, the report gives a thorough overview of the existing **AI market**, and most notable, open source AI and open source ML (Machine Learning) are gaining traction and widespread availability. Within this overview is also a discussion about the **ethical implications** of utilising AI in future technology development, and the EU has already established high-level bodies to lead the discussion about AI ethics.

On the topic of **Edge ML** and **Deep Learning**, the HiPEAC report emphasises the importance of Europe to collaborate with ICT edge and cloud initiatives. The report states that "it is foreseen that future HPC loads will not only be simulations with large floating points applications, but will encompass more and more big data and artificial intelligence, from data that will be provided in real time and pre-processed by edge devices." It envisions that this integrated technology scenario could lead to the use of machines as enablers for important scientific breakthroughs. The HiPEAC roadmap also assets that **deep-learning algorithms**, while they have seen rapid progress, could also face hard-computing restraints. It states that "high-performance computers with the help of GPU accelerators often run for days or weeks with very deep networks and extremely large learning sets."

According to the report, one important market trend shows that **Graphic Processing Units** (GPUs) are in huge demand and their cost has increased. As the importance of energy efficiency in high-performance computing (HPC) comes to the forefront of the discussion, more efficient hardware will be required. HiPEAC states that "GPUs are the first step of specialization compared to general-purpose processors: they are designed for throughput and have less flexibility in terms of control units." Cloud computing is also still trending as a means of increasing efficiency, and the report points out the cloud computing models need to be aware of enhancing their privacy for users. It adds that one important emerging business opportunity is encryption services for such data.

Under this same context of Challenge 2 from the ECSEL SRA, the emergent **5G network** for mobile communication was extensively discussed. One novel aspect of the advent of this network is that "5G connectivity aims to reduce energy usage by 90 %," and will be designed to function in "longer power-efficient deep sleep states that have low energy consumption and more efficient data transmission." HiPEAC states that the impact of such a new network will result in "enhanced mobile broadband applications, ultra-reliable low-latency communications, and massive machine-type communications" and that the system embodies the full computing spectrum; from edge through fog to cloud.

In general, HiPEAC's vision for the position of Europe in regard to this named Challenge 2 will be that **Europe become the leader in "intelligence at the edge solutions"** and will "consider ICT domains as a continuum, not as silos." A threat named to this the vision will be that the computing infrastructure may be subject to attack from the edge to the cloud (such as the case with previous ransomware attacks, which could upset several important systems. However, as a building block to reach this vision,

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the HiPEAC report advocates that developers in this sector continue to "shift towards the edge" and that investment in training for employment in these fields will be very important to achieve this vision.

Condition monitoring, decision making (Challenge 3)

This challenge is not mentioned explicitly but decision-making is related to data analytics, which is mentioned in relation to edge computing and high-performance data analytics.

Digital platforms (Challenge 4)

In contrast to the other ECSEL challenges listed, the HiPEAC report does includes much discussion about the importance of designing hardware platforms that can also be automated. It states that "**Europe should invest in an ecosystem of tools to design accelerators**." In particular, it highlights the important of start-up accelerators. The HiPEAC roadmap argues that accelerators should not be started from scratch, but rather, their design cost should be lowered, and should utilize open-source designs that are adaptable to business and user needs. This is of particular importance for SMEs, since it will bring accelerator design closer in reach for them.

The HiPEAC roadmap considers accelerators as tools with requiring both hardware and software components, and suggests that even "**advanced AI-related techniques** could explore the space of solutions under the control of the designers. HiPEAC stresses **that open source design for digital platforms** are of the utmost importance, since they will aid in "promoting the appearance of innovative and new solutions in Europe." Additionally, the report envisions that **open source platforms build trust, democratises new solutions**, and create new ICT ecosystems, which are an important drive in the industry. The report reflects on the fact that the original success of the PC was due to "the numerous software that could run on the platform." Even now, many GAFAM + BATX tech giants have found their success, due to independent developers making applications and usages of their hardware. As HiPEAC states, "two ecosystems exist" on the digital platform, which will continue to be vital in the field of digital innovation.

Cross-cutting aspects present in ECSEL:

The HiPEAC report includes several cross-cutting aspects that are in line with other topics discussed in the ECSEL SRA report. On the topic of **interoperability**, the report states that this poses challenges for **IoT and CPS**. It states that "Unless a customer buys all his devices from the same company, they need to download a special app to control a new device." This siloed-domain structure is in direct contrast to what consumers want (integrated applications) and will pose a challenge for the new markets. The roadmap finds that in general in the markets, voice activated IoT devices have become more common, but wearable devices have not taken off as expected. HiPEAC states that this may be due to "the short life of the battery, privacy concerns, and, above all, a failure to see the benefit of such devices." These will be further hurdles to overcome.

In further relation to **IoT and CPS**, the HiPEAC roadmap identifies that there is a need for **standards** and **regulations** in these two domains, as they are soon to be widely used and can benefit almost any sector. **Security** is another cross-cutting theme that emerges often in the report, since the industrial

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IoT is particularly vulnerable to such attacks (for example, ransomware) and planning preventative “**security by design**” should be considered. HiPEAC also points out that cyber-physical systems have the additional challenge of ensuring safety, so that the system will not harm the environment. Overall, the HiPEAC roadmap says that CPS has become so prevalent in the industry, that is it “now the norm rather than the exception.”

The HiPEAC roadmap also includes a list of **opportunities** that touch on some cross-cutting themes (e.g. embedded systems, IoT, CPS, and Cybersecurity). Moreover, under the subtopic of **Societal Vision** the report mentions the three following topics:

- Digital ethics should guide us to the future
- Employment will evolve
- Digital skills are the fuel of innovation

2.3.7.3 Emerging trends and potential gap with the ECSEL SRA

The HiPEAC report identifies some important **Emerging Trends** in both technical and non-technical realms that were not present in the ECSEL SRA roadmap:

Technical Trends:

- Blockchain as both an important business trend, and a means of data protection
- Learning platform trends like MOOCS (Massive Open Online Courses) and flipped classroom
- Networks on Chip (NoC)
- Inter-rack communication (e.g. Unshielded Twisted Pair (UTP) cable connections between racks
- Wireless 5G
- Storage in terms of volatile memories and non-volatile memories

Societal/Innovation related:

- The addictiveness of digital platforms and how social media affects the health of humans
- The spread of fake news and impact on society
- Privacy erosion

In the next decade, HiPEAC predicts that end users will embrace these flexible electronics and “will personalize the sensing and intelligence of wearable/IoT devices by selecting sensors, their interfaces, and customizing flexible systems to applications.” It is expected that this new market will bring unprecedented effects to industry and research communities and allow for novel market and business opportunities for SMEs. Overall, the HiPEAC report estimates that the printed sensor market will be worth £6.4bn in 2025.

Gaps:

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Perhaps the most important and visible gap present in the HiPEAC report is the discussion of how various aspects of the ICT domain can be used to solve aspects of each of the 17 Sustainable Development Goals (SDGs). In particular, the HiPEAC roadmap indicates that advanced computing can be used as an **enabler of sustainability**, and that technologies must reduce their ecological footprint. This insight touches on several of the key challenges listed in the ECSEL report and is a vital aspect of the future of digital innovation.

In addition to this contribution, the HiPEAC report also does a thorough **market analysis** and subsequently **SWOT analysis** about Europe’s comparison to the rest of the world. This was useful, as it gave context to what areas are most essential to prioritize. Finally, one last gap that is present in this report was its discussion of education in ICT and its **impact on the future job market**, as well as the **future of education**. This lens was very useful in further understanding Europe’s context and high-priority focus areas.

In relation to the third challenge listed in the ECSEL SRA report, the HiPEAC findings are unique in that they discuss many of the **environmental impact** related to the production of devices. For example, emerging electronics that are used in IoT sensor devices, the environmental impact is significant, and the footprint of producing such devices must be accounted for and drastically reduced in the near future. The HiPEAC report also discusses how the advancement in such sensors will allow for great advancements in the medical devices and wearable electronics sectors, but the report also predicts that there will be a learning curve in these markets for the next 10-15 years.

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2.3.8 The Industrie 4.0 (German initiative)

2.3.8.1 Summary

This Industrie 4.0 implementation strategy was drawn up by the Industrie 4.0 Platform (organised by the associations Bitkom, VDMA, ZVEI) in partnership with companies from German industry as well as other associations. It therefore serves to prepare Germany and its industry for the challenges of the future. The implementation strategy addresses readers from German industry, the relevant high-tech sectors, research and politics. In particular, managers, specialists and advisers are addressed as are all persons interested in or who would like to help shape the forwarding-looking vision embodied by Industrie 4.0 in Germany. This publication has been seen as a model to build the foundation of other European roadmaps for digital innovation in regard to manufacturing and industry 4.0.

Chapter 2 of the document gives an overview of Industrie 4.0 and outlines the industry association's strategy and goals for the joint Industrie 4.0 Platform to continue the activities of the German Science and Industry Research Union (Forschungsunion Wirtschaft-Wissenschaft) and to develop a coordinated, cross-sector course of action. Their 8 main goals are as follows:

- Standardisation
- Management of complex systems
- Area-wide broadband infrastructure for industry
- Safety
- Work organisation and workplace design
- Training and further training
- Legal framework conditions
- Resource efficiency

In order to transform industrial production to Industrie 4.0, a dual strategy will be pursued in Germany. First, the German equipment industry will continue to be a leader on the world market by becoming the foremost provider of intelligent production technologies through the dedicated consolidation of information and communication technology and the typical high-tech strategies they use. New leading markets for CPS technologies and products must be defined and harnessed.

Second, the continued development of German manufacturing by means of efficient, resource-saving production technologies will be required to make it both attractive and competitive. The goal is to expand the competitive advantages of companies in Germany through close physical proximity and active networking of users and manufacturers via the Internet. Automation, process and production technology in Germany will also benefit equally from this strategy

Chapter 3 of the Roadmap contains propositions form the scientific advisory board, in the areas of People, Technology, and Organisation. The core elements of Industrie 4.0 are described in Chapter 4 of the roadmap. In Chapter 5, "Research and innovation", is used to determine important needs for

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research and describe them in the form of research roadmaps and specifications. Also contained in this chapter are listed Key Milestone and their anticipated methodology, solutions, and prerequisites, as well as timeframes.

A reference architecture model for Industrie 4.0 (referred to in short as RAMI 4.0) is presented in Chapter 6, which describes the structure of the Industrie 4.0 components and how they work. Lastly, Chapter 7 outlines the special security requirements that will arise due to increased networking and controllability of physical objects as well as the growing threat of hackers, intelligence services, espionage etc.

2.3.8.2 Analysis

Digital twins, simulations (Challenge 1)

The document "Implementation Strategy for Industry 4.0" contains the results of a working group at the German national level. In regard to Challenge 1, as identifies by the ECSEL SRA report, the document touched on several of the content related to simulations and digital twins. Namely, the report identified one Key Milestone as the "Automation of Values Networks" and as a part of reaching that milestone, name "Use of methods for **modelling, calculation, simulation** and optimisation" as an important methodology for achieving that milestone. Additionally, the report includes much discussion about systems engineering, and identified simulation as an important component of that. The sub-topic of **virtual commissioning** was also discussed as an important part of both the **factory and machine life cycles** for pre-operating Industry 4.0 requirements.

The Implementation Strategy for Industry 4.0 document also identifies some new opportunities to pursue in relation to the overall development of Industry 4.0. It states, "The networking and individualisation of products and business processes leads to complexity, which is managed by means of modelling, simulation and self-organisation." In regard to **digital twins**, the Implementation roadmap describes a similar structure that is part of the RAMI-architecture, and the important of the communication interface between its components. It highlights the importance of an "**administrative shell**" for this communication purpose, which "**contains all data of the real component like a digital twin**". Furthermore, the document recommends to the Advisory Board of the working group that utilizing such simulations will lead to "a greater scope for solutions can be analysed faster so that solutions can be found sooner."

AI, machine learning, big data (Challenge 2)

Of the many subtopics under the umbrella of Challenge 2, the Implementation Strategy for Industry 4.0 report concentrated heavily on the theme of **big data**. Key milestones identified in the publication that intersect with these topics included the following:

- Research on intelligence, flexibility, adaptability
- Research on the topic of "Data analysis"
- Research on network communication for Industry 4.0

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In particular regard to the last milestone, it is necessary to complete "100Gb/s 5G Network infrastructures", and to "design and standardise the 5G Network infrastructure as well as new radio standards and near field technologies." In addition to this expected achievement, the report also states that "Industrie 4.0 compliant communication must be performed in such a way that the data of a virtual representation of an Industrie 4.0 component can be kept either in the object itself or in a (higher level) IT system."

Condition monitoring, decision making (Challenge 3)

Regarding Challenge 3, the Implementation Strategy for Industry 4.0 publication covers a few of the related subtopics. Major themes that appeared in the report include:

- Sensor networks
- Data analysis
- Importance of standardization
- Syntax and semantics (descriptive language)

The report especially lists one key milestone as 'sensor networks' and discusses the importance of data analysis as a **decision making** aid, along with **autonomous decision making**, described as "which information is provided to whom and when" and can help companies to increase the quality of their products and the efficiency of their production as well as to quickly identify any undesirable developments. The German Implementation Strategy for Industry 4.0 document also identifies the relevant opportunity of "resource effectiveness and efficiency can be continuously planned, implemented, monitored and autonomously optimised" in relation to autonomous decision-making.

The publication also deals heavily with clarification and streamlining of descriptive language used and real-time analysis used in Industry 4.0, and listed the following expected achievements under the context of Challenge 2:

- Uniforming semantics and syntax data
- Quality of service for Industry 4.0 components, such as real-time capacity, fail safety, and clock synchronisation

To match these expected achievements, the report lists several expected outcomes, mostly related to the sub-topic of real-time analysis. They include the following:

- Online regulation of a manufacturing process dependent on traced real-time data from the process as well as the quality of the process output
- Requirements management with respect to bandwidth, determinism and real-time
- Embedded systems on chip including special processors, special real-time capable microcontrollers and high-tech storage offering high performance and minimal power consumption as well as multi-core architectures
- Alignment to specific use cases and real-time transfer to applicable events to demonstrate practical suitability.

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Digital platforms (Challenge 4)

To address Challenge 4, the topic of digital platforms was mainly discussed in the context of RAMI4.0, the Reference Architecture Model for Industrie 4.0, which in itself can be seen as a framework for digital platforms. Moreover, the report does list some related expected achievements related to the structure of platforms. These consist of:

- Detection and response capabilities are part of the basic setup
- Detection capabilities within the office domain must be developed and made available for the production realm
- Define the concept of an Industrie 4.0 component in such a way that it can meet requirements with different focal areas, i.e. “office floor” or “shop floor”.

Some opportunities are identified in the German implementation report include platforms/systems that are “addressable and identifiable inside production means” and that “support the virtual planning of production systems and processes” while offering “their functions as services that others can access.” In the report, digital platforms are considered important learning tools and practical artefacts that can “automatically impart their functionality to the user.” The Implementation Strategy for Industry 4.0 report also elaborates in-depth about the RAMI4.0 platform.

The Reference Architecture Model for Industrie 4.0 (**RAMI4.0**) contains “the fundamental aspects of Industrie 4.0”, and expands the hierarchy levels of IEC standards by adding the "product or workpiece" level at the bottom, and the “connected world” that extends individual factory boundaries at the top. The RAMI4.0 model is the digital representation of a combination of life cycle and value stream with a hierarchical approach. The model (Figure below) is structured into the following layers:

- **Vertical Axis** - represents various perspectives, such as data maps, functional descriptions, communications behaviour, hardware/assets or business processes
- **Horizontal Axis** - the product life cycle with the value streams it contains
- **Third Axis** - the location of functionalities and responsibilities within factories/plants.

The aim of RAMI4.0 is to cover the issues with as few standards as possible. It is anticipated that RAMI4.0 will be the **common standard** of the Industry 4.0 domain.

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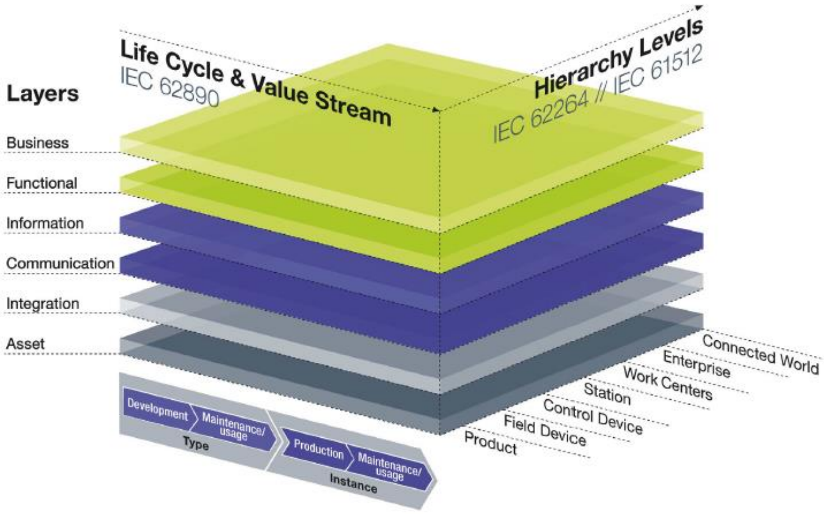

Figure 15: **Reference Architecture Model Industrie 4.0 (RAMI 4.)**

Cross-cutting aspects present in ECSEL:

The German Implementation Strategy for Industry 4.0 is structured relatively differently from the other European roadmaps, and as such is contains mostly discussion focused on cross-cutting aspects, more so than the four main challenges presented in the ECSEL SRA roadmap. Most notably, the report listed several key milestones that fall into additional subtopics. They are as follows:

- Research on methods and new business models
- Values networks framework
- End-to-end nature, engineering over the entire life cycle
- Systems engineering
- Research on the acceptance of technology and the -organisation of working practices
- Milestones for research on micro-electronics

Overall, one of the major cross-cutting themes highlights in the report is **cyber security**. The Implementation Strategy for Industry 4.0 roadmap contains a whole chapter on the possible threats posed to Industry 4.0 systems, including:

- Malware attacks
- Infiltration of company assets
- Attack software from espionage groups
- Indirect attacks on availability
- Attacks on safety function
- Data theft and confidentiality
- Manipulation (intended of unintended)
- Identity theft

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In particular, the report identifies value networks themselves as potential targets of attacks, and predicted that safety functions are becoming increasingly vulnerable. To combat this, it made recommendations that Industry 4.0 systems be embedded with '**security by design**' and that security of data storage be a top priority. In terms of expected achievements, the Implementation Strategy roadmap indicates that security by design could be achieved in the areas of:

- Availability
- Integrity
- Protection of expertise/confidentiality
- Authenticity
- Integrity of time- esp. With value networks
- Traceability
- Legal Security

In terms of opportunities, the German implementation Strategy roadmap lists both opportunities for organisation, as well as people-focused opportunities. In regard to organisation, it lists the following priorities:

- New and established **enhanced value networks** integrate product, production and service while enabling dynamic variation with respect to the division of labour.
- Cooperation and competition lead to **new structures** both at commercial and legal levels.
- System structures and business processes can be mapped onto **valid legal frameworks**; new legal solutions permit new contractual models.
- There are opportunities for arranging **regional value creation** – also in **developing markets**.
- A new **security culture** will lead to **trustworthy, resilient and socially accepted** Industrie 4.0 systems.

In the theme of people-focused opportunities, the following objectives were listed:

- A wide variety of possibilities for **a human-centred approach to work** will arise, also in the sense of self-organisation and autonomy.
- Offers opportunities for **organizing working practices** to account for aging and **different age groups**
- Industrie 4.0 as a **sociotechnical system** offers the opportunity of expanding the range of tasks handled by employees
- Raises employee **level of qualifications** and scope of action, and significantly increases their **access to knowledge**.
- "**Learnstruments**" and "**communities of practice**" increase productivity in both teaching and learning

Lastly, it is worth noting that the Implementation Strategy for Industry 4.0 roadmap includes some important recommendations in regard to implementing aspects of Industry 4.0 in accordance with **ISO/IEC standards**. This was a feature of this report that is an important consideration when making recommendations.

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2.3.8.3 Emerging trends and potential gap with the ECSEL SRA

Emerging Trends

The most prominent emerging trend of the Industry 4.0 Implementation Strategy roadmap is its in-depth description of the importance of **systems engineering**, as well as the subtopics of **standardization, semantics, and (reference) architecture systems**. In particular, it frequently mentioned the RAMI4.0 (Reference Architecture Model for Industry 4.0) described above. In terms of security, the roadmap includes an important discussion on **security by design** for Industry 4.0.

Potential Gaps

The most prominent gaps in the Industry 4.0 Implementation Strategy roadmap in comparison with the ECSEL SRA are its in-depth focus on the aspects of **standardisation** for Industry 4.0, as well as its discussion of the importance **of nestable, separable logical aspects**.

2.3.9 2018 World Manufacturing Forum Report: Recommendations for the Future of Manufacturing

2.3.9.1 Summary

The 2018 WMF Report examines societal megatrends such as Demographic changes: ageing population and Generational Gap and Lack of Young Talent; Enhancing Workforce Diversity: Women, disabled persons, Foreign-Born Workers, Digital Divide, Cybersecurity; Urbanisation: Worldwide Migration and Growing Urban Population; Environmental Megatrends: Climate Change and Scarcity of Natural Resources. And nine significant manufacturing challenges: competences and skills gap for advanced manufacturing, global-local agile supply chain networks, integration of IT, OT and ET, scarcity of natural resources and reduction of energy consumption, mass personalisation, hybrid and smart materials, data-driven manufacturing, data security and data authority, and SMEs' digital divide. It considers six disruptive trends: Inclusive Manufacturing, Cognitive manufacturing, Global Risks-Resilient Manufacturing, Hyper-Personalised Manufacturing, Circular Manufacturing, and Rapidly Responsive Manufacturing.

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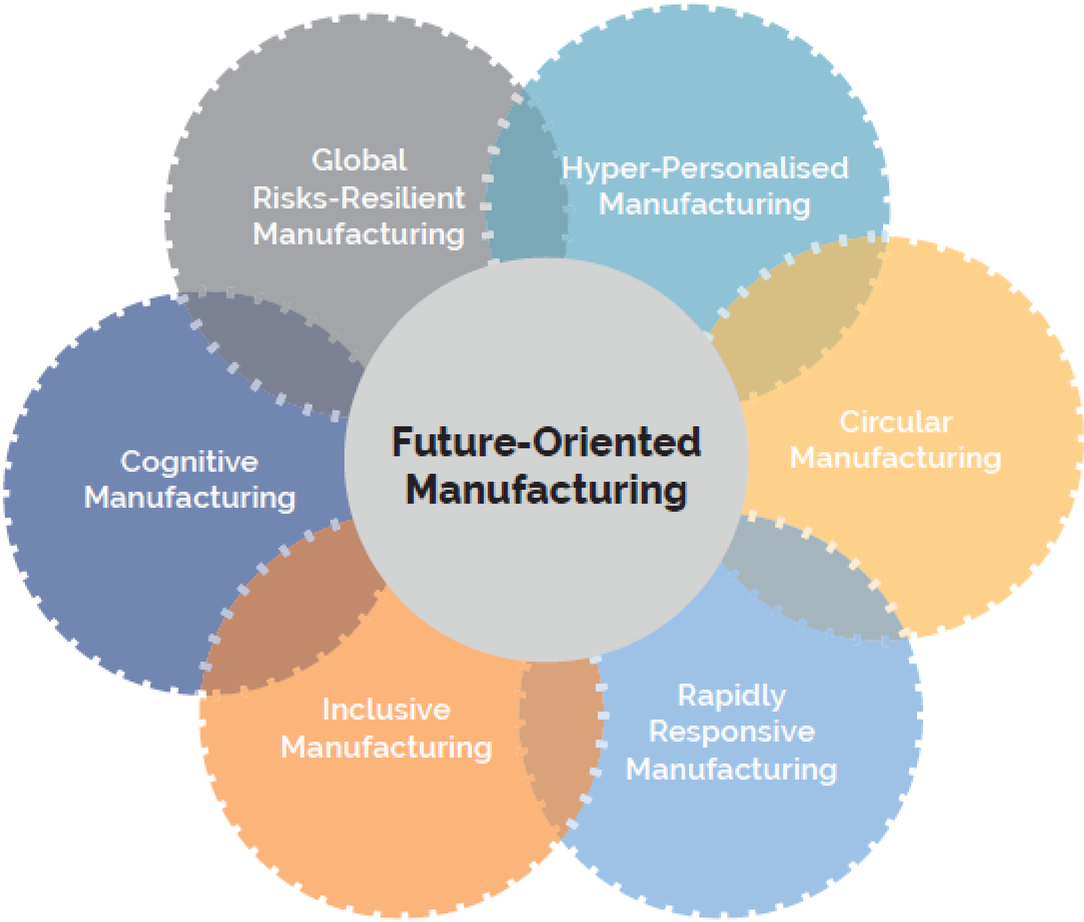

Figure 16: Future-oriented manufacturing trends

Each of these manufacturing trends is more elaborated with key points to address:

Cognitive manufacturing:

- Hyper-Connected Intelligent Machines
- AI-Driven Cognitive Operations
- Smart Optimisation of Resources
- Collaborative Manufacturing as a Service in the Cloud

Hyper-Personalised Manufacturing

- Embed sensors into goods and create mechanisms to use that direct feedback on usage to develop more personalised products
- Use 3D printing to accelerate prototyping and testing which can drastically speed up the time to market and responsiveness to changes in consumer demand
- Create manufacturing processes which are flexible enough to adapt products to rapidly shifting consumer tastes and trends

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- Develop ways to involve customers in the design of products.

Global Risks-Resilient Manufacturing

- Reinforcing Cybersecurity
- Exploiting Social IoT Systems
- Integrating Blockchain Technologies
- Involving All Stakeholders in the Digital Value Chain
- Responding to Off-Shore Threats

Circular Manufacturing

- Redesign Products and Materials Selection Suitable for Reuse
- Conserve and Recover Resources from the Used Products, and Use them in Manufacturing of New Products
- Develop New Ways of Production
- Implement a Service-Based Model for Circular Products
- Shift from Fossil to Renewable Raw Materials and Eliminate Use of Toxic Chemicals

Inclusive Manufacturing

- People-Oriented Innovation
- Environment-Oriented Innovation
- Technology-Oriented Innovation

Rapidly Responsive Manufacturing

- Agile, Adaptive, Responsive and Robust Manufacturing Capabilities
- Digitally Empowered Factory Operations
- Flexible Production Systems and Supply Chains
- Rapid Product Realisation
- Repetitive Manufacturing Ability

Further, the 2018 WMF Report proposes the key recommendations to be adopted by manufacturing stakeholders globally:

1. Cultivate a Positive Perception of Manufacturing
2. Promote Education and Skills Development for Societal Well-being
3. Develop Effective Policies to Support Global Business Initiatives
4. Strengthen and Expand Infrastructures to Enable Future-Oriented Manufacturing
5. Encourage Eco-Systems for Manufacturing Innovation World-Wide

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6. Create Attractive Workplaces for All
7. Design and Produce Socially-Oriented Products
8. Assist SMEs with Digital Transformation
9. Explore the Real Value of Data-Driven Cognitive Manufacturing
10. Promote Resource Efficiency and Country Specific Environmental Policies

2.3.9.2 Analysis

The analysis has been made following the topics of the 4 challenges (and subtopic) of the digital industry chapter of the ECSEL SRA as well as cross-cutting aspects.

Digital twins, simulations (Challenge 1)

This challenge is not explicitly mentioned in the 2018 WMF Report

AI, machine learning, big data (Challenge 2)

"Cognitive manufacturing" trend is very related to this challenge as well as three of its four focused ways: Hyper-Connected Intelligent Machines, AI-Driven Cognitive Operations and Smart Optimisation of Resources

"Data-driven manufacturing" challenge is also very related. As well as the "Explore the Real Value of Data-Driven Cognitive Manufacturing" recommendation.

Condition monitoring, decision making (Challenge 3)

Predictive maintenance is mentioned as a service in the report but not further elaborated. For instance, "Exploiting Social IoT Systems", one of the pillars of Global Risks-Resilient Manufacturing challenge, is seen as enabler for maintenance.

However, "Data-driven manufacturing" is a hot topic in the report.

Digital platforms (Challenge 4)

"Integration of IT, OT and ET" manufacturing challenge is very related to digital platforms.

Cross-cutting aspects present in ECSEL: Cyber-physical systems, IoT, SoS, Electronic Components and Systems, semicon, cyber-security, connectivity, interoperability, etc.

Topics related to security are addressed:

- Data security and data authority challenge
- Reinforcing Cybersecurity from Global Risks-Resilient Manufacturing challenge
- Integrating Blockchain Technologies from Global Risks-Resilient Manufacturing challenge

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Topics related to servitisation and cloud:

- Collaborative Manufacturing as a Service from Cloud of Cognitive manufacturing challenge

Topics related to sensors:

- Embed sensors into goods and create mechanisms to use that direct feedback on usage to develop more personalised products from Hyper-Personalised Manufacturing challenge.

2.3.9.3 Emerging trends

Design principles

Regarding design principles, Hyper-Personalised Manufacturing trend could be mentioned: "Hyper-Personalised Manufacturing takes personalisation to the next level by analysing information in the public domain to create unique, precise, and personalised offerings of products and services that are highly tailored to the requirements and needs of consumers, evolving into a customer-centric business environment capable of developing customised products for both local and global markets to build greater trust with their customers".

Personalization and customization are mentioned in the ECSEL SRA but not explicitly in the Digital Industry chapter.

Technology trends

Regarding the technological trends, this report mentions topics related to

- Use 3D printing to accelerate prototyping and testing which can drastically speed up the time to market and responsiveness to changes in consumer demand

In the ECSEL SRA, additive manufacturing and 3D printing is mentioned but not explicitly in the Digital Industry chapter where challenges and research topics are explained.

Paradigm shifts / impact aspects / drivers / social aspects

The 2018 WMF Report examines societal megatrends that are drivers to be considered such as Demographic changes, Enhancing Workforce Diversity and Environmental Megatrends. Moreover, several of the manufacturing trends are coming from these drivers such as Inclusive Manufacturing, Global Risks-Resilient Manufacturing and Circular Manufacturing. The topic "Involving All Stakeholders in the Digital Value Chain" from Global Risks-Resilient Manufacturing challenge and the recommendations to create Attractive Workplaces for All and Design and Produce Socially-Oriented Products are related to those social drivers and trends.

Regarding education, competences and skills gap for advanced manufacturing is one of the identified challenges and to Promote Education and Skills Development for Societal Well-being one of the recommendations.

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The SMEs' digital divide is also one of the identified challenges and to assist SMEs with Digital Transformation one of the recommendations.

3 Identified gaps and emerging topics

This section presents preliminary gaps and topics identified after the analysis of the roadmaps. The gaps and topics identified in the first iteration were further elaborated in Task 1.2 Identification of gaps and emerging themes.

The following emerging themes have been identified:

- Human centred manufacturing:
    - Human machine relation, interaction, collaboration, complementarity
    - Human-in-the-loop, human as part of the system and HMI including intuitive systems, wearable and implantable systems, virtual and augmented reality as well as human machine collaboration and collaborative decision making
    - New engineering tools considering humans as part of the systems
    - Human machine / human robot collaboration, enhanced role of workers and customers in manufacturing
    - Manufacturing as networked, dynamic socio-technical systems, HUMANufacturing as a new era of automation and human interaction, customer-centric value creation networks
    - Human driven innovation, co-creation through manufacturing ecosystems, customer driven manufacturing value networks, social innovation
    - Hyper-personalised manufacturing, human in the loop, inclusive manufacturing
- Sustainable manufacturing in a Circular Economy
    - Electronic Components and Systems (ECSs) could have a great impact in reducing the impact in the environment through sustainable manufacturing including energy and resource efficiency and applying circular economy strategies: eco-design, repair, reuse, refurbishment, remanufacture, recycle, waste prevention and waste recycling, etc. This impact is from two perspectives: From one side, the ECS as the product itself to repair, reuse, recycle… and from the other side, the ECS as enablers to improve sustainability and support circular economy in manufacturing.
        - Responsible value creation in a Circular Economy, sustainable manufacturing
        - Sustainable manufacturing: innovative processes and systems for sustainability in terms of energy and resource consumption and impact in the environment
- Multi-technology co-engineering enabled by digitalization
    - Parallel joint engineering of products, processes, safety, security, cybersecurity, human factors, sustainability, circular factors, etc.
    - Mastering the deep linkage and complexities about multiple engineering domains and technologies, along with product and process lifecycles. In the digital domain.
    - Multiplying the engineering extent, efficiency and quality in the digital world.
- AI enabled cognitive, resilient, adaptable manufacturing; socio-technical system (extension of MC2)
    - This new major challenge is extended towards AI enabled, adaptable, resilient factories including the human as a part of the 'socio-technical' system. AI in combination with (predictive) condition monitoring and maintenance will be applied

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    to not only support reconfigurable first time right / zero defect manufacturing, but also support human decision making (considering uncertainties) as well as enable resilient manufacturing ecosystems based on new business models.
  - Gaps in regards to other roadmaps include the following topics, which should be discussed in relation to how electronic components and systems can play a role:
    - (Big) Data Analytics, AI / machine learning
    - AI/Condition monitoring for high quality outcomes
    - Cognitive, resilient factories, supply chains, value creation networks:
    - AI and Human in the Loop, Human as part of the resilient factory
    - AI, condition monitoring for Circular Economy
    - AI and Business
    - AI and skills
- Modelling and Simulation (Digital twin and wider context, extension of MC1)
  - The analysis of different roadmaps (and discussions with experts) revealed, that on the one hand, the 'digital twins' referred to within the ECS SRA could be extended toward 'other twins', the methods for modelling and simulation could be extended and detailed and the scope of applying the digital twin/methods for modelling and simulation could be widened towards including the human in the loop, and the product life-cycle towards a circular economy approach (from cradle-to-cradle). Moreover, the digital twin can support new business models.
  - Gaps in regards to other roadmaps include the following topics, which should be discussed in relation to how electronic components and systems can play a role:
    - Further methods for modelling and simulation
    - Human in the loop
    - Circular Economy
    - Standardisation
    - Business models
    - Skills

And the following non-technical themes have been identified:

- Skills development, re-skilling, up-skilling
  - T-shape, cross-disciplinary education, lifelong learning and (re-/up-) skilling
  - Competence management, trained and highly educated workforce, continuous training
- Business models:
  - New business models in value creation networks
- Standardisation
  - Reference Architectures and Models, Implementation of RAMI, Standardisation
- Others
  - Legal framework conditions
  - Ethics, social and environmental impacts (positive and negative)

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4 ECSEL lighthouse projects

This section will define the criteria for assessing the ECSEL Industry4.E Lighthouse projects, a summary of those projects and an assessment of them, taking into account the criteria defined.

4.1 Classification criteria for assessing projects

Three items from the ECSEL's SRA 2019 [1] have been used to assess the projects:

- The key application areas (see Figure 17): Transport and Smart Mobility, Health and Well-being, Energy, Digital Industry and Digital Life.
- The essential capabilities (see Figure 17): Systems and Components: Architecture, Design and Integration; Connectivity and Interoperability; Safety, Security and Reliability; Computing and Storage; and Process Technology, Equipment, Materials & Manufacturing for ECS.
- The challenges identified for the Digital Industry:
  - Major Challenge 1: Developing digital twins, simulation models for the evaluation of industrial assets at all factory levels and over system or product life cycles.
  - Major Challenge 2: Implementing AI and machine learning to detect anomalies or similarities and to optimize parameters.
  - Major challenge 3: Generalizing condition monitoring, to pre-damage warning online decision-making support.
  - Major challenge 4: Developing digital platforms, application development frameworks that integrate sensors and systems.

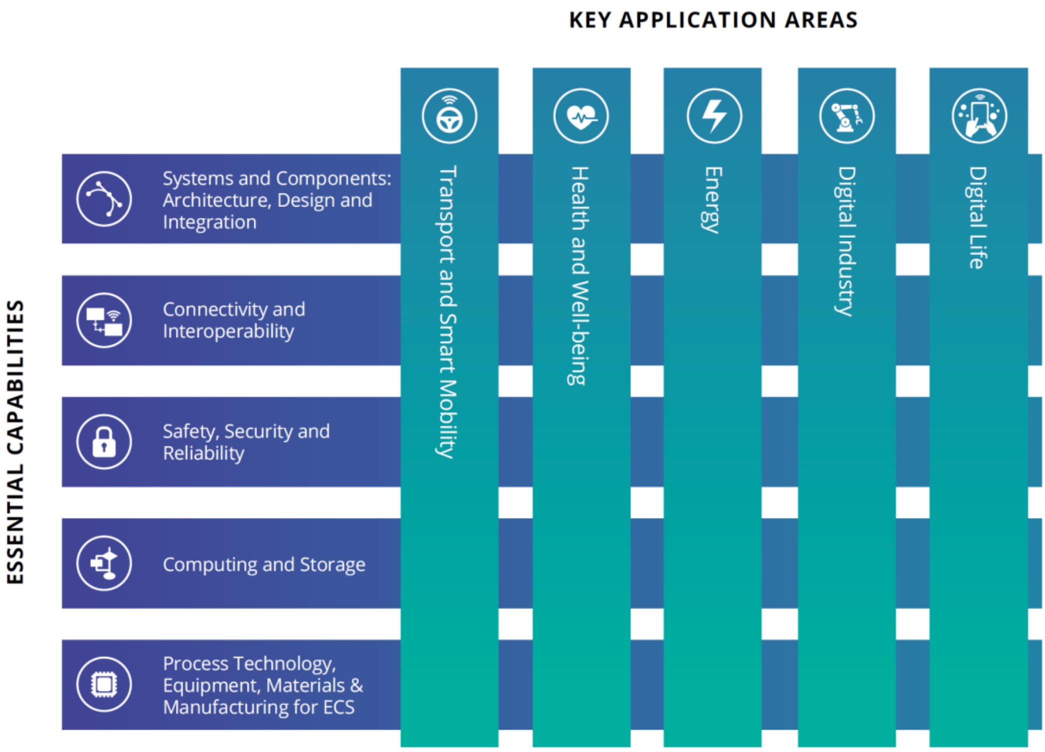

Figure 17: Key application areas and essential capabilities of ECSEL SRA, from [1]

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4.2 Brief description of the projects

This section presents a brief description of all the projects in the Industry 4.E lighthouse presented ordered by their starting date. For more information about the projects, see annex in section 0.

- **Mantis: Cyber Physical System based Proactive Collaborative Maintenance:** The project will develop a Proactive Maintenance Service Platform Architecture based on Cyber Physical Systems that enable “Collaborative Maintenance Ecosystems”.
- **SWARMs: Smart and Networking Underwater Robots in Cooperation Meshes:** The primary goal of the SWARMs project is to expand the use of underwater and surface vehicles (AUVs, ROVs, USVs) to facilitate the conception, planning and execution of maritime and offshore operations and missions.
- **SemI40: Power Semiconductor and Electronics Manufacturing 4.0:** The implementation of Industry 4.0 technologies is the key aspect of SemI40 project, to enhance sustainable competitiveness in European electronics and semiconductor production, adopting recent innovations in electronic systems and ICT technologies.
- **Delphi4Led: From Measurements to Standardized Multi-Domain Compact Models of LEDs:** The main objective of Delphi4LED is to develop a standardized method to create multi-domain (thermal-optical-electrical) LED based design and simulation tools for the solid-state lighting industry.
- **Productive 4.0: Electronics and ICT as enabler for digital industry and optimized supply chain management covering the entire product lifecycle:** The main objective of Productive4.0 is to achieve improvement of digitalizing the European industry by electronics and ICT.
- **SCOTT: Secure Connected Trustable Things:** SCOTT will provide comprehensive cost-efficient solutions of wireless, end-to-end secure, trustworthy connectivity and interoperability for Internet of Things.
- **I-MECH: Intelligent Motion Control Platform for Smart Mechatronic Systems:** The I-MECH target is to provide augmented intelligence for wide range of cyber-physical systems having actively controlled moving elements, hence support development of smarter mechatronic systems.
- **AFarCloud: Aggregate Farming in the Cloud:** AFarCloud will provide a distributed platform for autonomous farming, which will allow the integration and cooperation of Cyber Physical Systems in real-time for increased agriculture efficiency, productivity, animal health, food quality and reduced farm labour costs.
- **iDev40: Integrated Development 4.0:** iDev40 introduces seamlessly integrated ECS development processes, safe and secure digital automation workflows, interoperable and inter-organizational network solutions as well as an enhanced transparency of data and intelligence that will lead to a reduction in the time to market (T2M) race for ECS solutions.
- **MADEin4: Metrology Advances for Digitized ECS industry 4.0:** The goal is improving metrology in industries across the electronic components and system (ECS) value chain and in any Cyber Physical Systems (CPS) which consist of metrology equipment, virtual metrology or Industrial internet of things (IIoT) sensors, edge and high-performance computing (HPC).

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- **Arrowhead Tools: Arrowhead Tools for Engineering of Digitalisation Solutions:** Engineering processes and tool chains for cost efficient developments of digitalization, connectivity and automation systems solutions in various fields of application for the further and wider commercialisation of automation and digitalisation services and products based on SOA, Arrowhead Framework and similar technologies.

4.3 Analysis of lighthouse projects

This section presents the mapping of the lighthouse projects regarding the criteria of key application areas, essential capabilities and challenges of Digital Industry covered.

Disclaimer: We do not claim this analysis to be complete or precise as ECSEL projects are very broad and not all the activities are gathered in public documents. We have collected information from the website of the project, CORDIS, the ECSEL Framework, the ECSEL website, proposal document, etc. Information was also collected during the "Shaping the Future Lighthouse Industry 4.E" workshop held in Bucharest the 19th of June 2019 co-located with the ECSEL Symposium where Delphi4LED, Productive 4.0, Mantis, I-MECH, IDev40, MADEIn4, SCOTT and Arrowhead tools projects were presented and their coordinators filled information about exploitable results, collaboration activities and future lines. Moreover, for most of the projects the analysis has been contrasted with the coordinator or partners of the project.

During next tasks in WP1: Task 1.2 Identification of gaps and emerging themes and Task 1.3 Recommendations for next steps, interviews and workshops will be carried out with the coordinators of the projects, to get further information and identify the gaps.

4.3.1 Regarding the key application areas

In SWARMS, the main area is **Digital Industry** as the goal is to make underwater and surface vehicles (AUVs, ROVs, USVs) further accessible and useful, making autonomous maritime and offshore operations a viable option for new and existent industries. The applications demonstrated in the projects are related to **Health and Well-being** (applications in monitoring of chemical pollution) and also **Energy** (as many offshore applications are used for harvesting renewable energy).

In Mantis, the main area is also **Digital Industry** as the main topic is the predictive maintenance applied to different fields of maintenance in several Industry areas. Several of the use cases demonstrate the results in production asset maintenance. There are also use cases in Vehicle maintenance management (**Transport and Smart Mobility**), in Health equipment maintenance (**Health and Well-being**) and in maintenance of Renewable energy assets (**Energy**).

In SemI40, the main area is also **Digital Industry** as the project focuses on development of semiconductors as a tool to enhance smart manufacturing. Project uses CPS systems to develop secure communications across the supply chain.

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In Delphi4LED, the **Digital Industry** area is one of the main areas as the LEDs and LED-based product modelling, design and manufacturing is the topic of the project. The project has a clear impact in the **Energy** area as LEDs are energy efficient light sources and utilisation of smart lighting enable use of lighting only when needed. **Health and well-being** and **Digital Life** could as well be impacted by the projects as applied LEDs can be utilised in various lighting, guiding and informing solutions improving human health and well-being and be part of smart home solutions.

SCOTT project focuses in building trust in the Internet of Things in many domains such as Aeronautics, Automotive, Building & Home / Smart Infrastructure, Health, Rail and cross domain. Taking into account the application in Smart mobility: Road, air, rail and marine transport (**Transport and Smart Mobility**), application in Smart health (**Health and Well-being**), application in Smart energy (**Energy**), application in Smart production and manufacturing and industrial automation (**Digital Industry**) and application in Smart home/building (**Digital Life**), we can conclude that the results of SCOTT are applicable in all the key application areas.

In I-MECH, the main area is **Digital Industry**, as the project proposes an Intelligent Motion Control Platform for Smart Mechatronic Systems applicable to the production automation market. During the project the solution will be applied in use cases in high-speed/big CNC machining, additive manufacturing, semicon and high-speed packaging. There is also a use case in Healthcare robotics (**Health and well-being** area).

Productive 4.0's main area is **Digital Industry**. The project addresses various industrial domains like consumer electronics, automotive, machinery or logistics with one single approach, i.e. that of digitalisation.

The main application area of iDev40 project is **Digital Industry**, as the project's main goal is the digitalization of the electronic components and systems industry, closely interlinking development processes, logistics and manufacturing.

AFarCloud is also addressing **Digital Industry**[6]. The project is about creating sensors and digital services for agriculture.

MADEIn4 is oriented to improving metrology in industries across the electronic components and system (ECS) value chain and any Cyber Physical Systems (CPS) which consist of metrology equipment, virtual metrology or Industrial internet of things (IIoT) sensors, edge and high-performance computing (HPC). So, its main application area is also **Digital Industry**.

In Arrowhead Tools, the primary application area is **Digital Industry**. Arrowhead Tools addresses engineering methodologies and suitable integrated tool chains, for creating digitalization and automation solutions for industry. Moreover, the application use cases are from all the application areas: Application use case in railway transportation (**Transport and Smart Mobility**), Application use case in healthcare domain (**Health and Well-being**), Application use cases in Smart City and Energy Domains (**Energy**) and Application use cases in Smart home (**Digital Life**).

[6] The ECS SRA 2019 [1] considers digital farming as part of Digital Industry.

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In the Table 1 a summary of the mapping of the projects and the key applications areas is found.

All the projects address the Digital industry key application area as we expected. Some of the projects (SemI4.0, Productive 4.0, iDev40, AFarCloud and MadeIn4) only addresses this area whereas other projects are relevant or are applied in several areas (Swarms, Mantis, Delphi4led, SCOTT, I-MECH and Arrowhead Tools) being the digital industry the primary area in most of the cases.

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Table 1: Mapping of projects regarding key application areas (in green main area, in yellow other application areas)

		SWARMs	MANTIS	semi40	Delphi4LED	SCOTT	I-MECH	Productive 4.0	iDev40	afarcloud	MADEin4	Arrowhead Tools
		swarms.eu	mantis-project.eu	semi40.eu	delphi4led.org	scottproject.eu	i-mech.eu	productive40.eu	idev40.eu	afarcloud.eu		https://www.arrowhead.eu/arrowheadtools
Key Applications Areas	***Transport and Smart Mobility***											
	Health and Well-being											
	Energy											
	Digital Industry											
	Digital Life											

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4.3.2 Regarding the Essential capabilities

SMARMs addresses **System and Components: Architecture, Design and Integration** essential capability as the approach is to design and develop an integrated platform (a set of Software/Hardware components), incorporated into the current generation of underwater vehicles in order to improve autonomy, cooperation, robustness, cost-effectiveness, and reliability of the offshore operations. SMARMS also addresses **Connectivity and interoperability** essential capability as the development of an underwater communication framework and a semantic middleware for managing the interoperability, cooperation and coordination are also part of the project in order to facilitate the cooperation and the exchange of information between networked AUVs, ROVs and unmanned surface vehicles (USVs).

MANTIS project addresses **System and Components: Architecture, Design and Integration** and **Connectivity and interoperability** essential capabilities as Mantis projects aims at providing a reference architecture for predictive maintenance. This architecture focuses on data storage, cloud, interoperability, data analysis and visualization. MANTIS also addresses *partially* the **Safety, security and Reliability** capability as the reference architecture covers security aspects and the **Computing and Storage** capability as it is an essential part of data lifecycle.

SemI40 project addresses **System and Components: Architecture, Design and Integration** as the development of SemI40 sSI IIoT Gateway system for the legacy integration of smart sensors is part of the project. The project also addresses **Connectivity and interoperability** as primary focus areas of the project deal with automation, process optimization, sensor integration, etc. **Safety, security and Reliability** is addressed as the project provided reference demonstrator solutions for increased safety and robustness against cyber-attacks in vintage production environment. **Process Technology, Equipment, Materials and Manufacturing for ECS** capability is also addresses as one of the main areas of the project is semiconductor technology development.

Delphi4LED addresses **System and Components: Architecture, Design and Integration** with application of LED Components and Systems in Architecture, Design and Integration; **Safety, security and Reliability** as Reliability of LED components producing excess heat is comprehensive studied during project. Digital thermal models have developed for specific LEDs in project. And **Process Technology, Equipment, Materials and Manufacturing for ECS** as Processing and manufacturing technology can utilise created knowledge related to LEDs and created electronic/digital datasheet approach.

SCOTT's main essential capabilities are **Connectivity and interoperability** and **Safety, security and Reliability**. SCOTT's goal is to develop cost-efficient solutions of wireless, end-to-end secure, trustworthy connectivity and interoperability. And to extend the IoT ensuring safety and security, privacy and trustability. The project partially addresses **System and Components: Architecture, Design and Integration** with the development of smart sensors and actuators, as well as the development of smart control systems providing safe interfaces.

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I-MECH project addresses **System and Components: Architecture, Design and Integration**. I-MECH provides a cutting-edge reference motion control platform for non-standard applications where the control speed, precision, optimal performance, easy reconfigurability and traceability are crucial. As well as building blocks at motion control level: control, modelling & identification, monitoring & diagnostics… and building blocks at instrumentation layer: Smart sensors, smart actuators and smart power electronics. It also addresses **Connectivity and interoperability** essential capabilities providing connectivity of the building blocks through communication interfaces and real-time wireless sensors.

Productive 4.0 addresses **System and Components: Architecture, Design and Integration** as the project main goal is to design, deployment and validation of an Industry 4.0 responsive architecture that is both service- and event-driven in order to enhance situational awareness and exploit the capabilities of CPS, IoT and Machine-to-Machine (M2M) communication, coupling them with co-simulation, modelling and optimization tools. **Connectivity and interoperability** are also addressed: Hybridisation and synchronisation of factory automation by combining a bottom-up orchestration of CPSs and production systems with a top-down virtualization of production processes through digitised models that allow the (cloud-based) collaboration of different automation components towards continuous connectivity. **Safety, security and Reliability capability** is partially addressed: Data security and secure communications are addressed. A secure and robust communication environment will be built in order to meet the demands of the industry focusing on a number of topics along the full value chain to be exploited by industrial equipment suppliers. A safety manager is also being developed inside the Arrowhead framework. There are use cases working in semiconductor manufacturing use cases so **Process Technology, Equipment, Materials and Manufacturing for ECS** is also partially addressed.

iDev40 addresses **Process Technology, Equipment, Materials and Manufacturing for ECS** as the project focuses mainly in the development and enhancement of digital value chain, particularly in the semiconductor manufacturing sector. It also addresses **System and Components: Architecture, Design and Integration** and **Connectivity and interoperability.** The project objective deals with Digitalization across Product Lifecycles and aims for 'optimized life cycle and change management along the value chain (based on the development and integration of the Digital Twin concept).' One of the main project objectives is the Virtualisation of ECS value chains, which is the 'Smart development and seamless integration into smart production by providing ubiquitous access to information, easy collaboration facilities, and a virtual live representation of operational processes.' **Safety, security and Reliability** capability is also addressed, as one of main Project objectives is Data Management Systems, which aims to 'prove concept for security-capable data management and automatic knowledge base update including the demonstration of knowledge validation.'

AFarCloud project addresses **System and Components: Architecture, Design and Integration** as a whole cloud-based data collection and handling system is developed and **Connectivity and interoperability** as sensor to cloud, cloud to UI, server to server and data sharing between farms are addressed.

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MADEin4 addresses **Process Technology, Equipment, Materials and Manufacturing for ECS** essential capability as MADEin4 will improve the metrology to support all process steps towards the final production across the electronic components and system (ECS) value chain.

Arrowhead Tools project addresses **System and Components: Architecture, Design and Integration** and **Connectivity and interoperability** essential capabilities mainly. It addresses three challenges of System and Components: Architecture, Design and Integration capability: "*Challenge: Managing critical, autonomous, cooperating, evolvable systems"* through the provision of efficient procedures, tools and integrated tool chains for engineering, operational management, maintenance and evolution of service platform based digitalization and automation solutions in both design time and run time; "*Challenge: Managing complexity"* With integration of tools along the chain; and "*Challenge: Managing diversity"* Going from ISA-95 to RAMI4.0/IIRA solving SoS engineering and operation. Provision of training material (HW and SW) for competence update of industry personnel. And for **Connectivity and interoperability**, it addresses two challenges: *"Challenge: Enabling nearly lossless interoperability across protocols, encodings and semantics"* Maturing of core Arrowhead Framework systems including e.g. Smart Service Contract, ConsumerCodeGeneration, Autonomic orchestration/configuration, Legacy Integration, etc. And *"Challenge: Ensuring Secure Connectivity and Interoperability*" through development of tools verifying compliance with standards on security, safety and reliability, modelling high level metrics along the engineering process. Improving Arrowhead Framework to include Security Manager, Safety Manager and Autonomous security issue detection and mitigation. So, Arrowhead tools also addresses **Safety, security and Reliability capability.**

The main essential capabilities addressed in the project are summarized in the Table 2**. System and Components: Architecture, Design and Integration** and **Connectivity and interoperability** are one of the main capabilities in 7 products. **Safety, security and Reliability** is the main capability in 2 projects. **Process Technology, Equipment, Materials and Manufacturing for ECS** is the main capability in 4 projects. **Computing and Storage** is not addressed by any project as main capability.

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Table 2: Mapping of projects regarding essential capabilities (in green main capability, in yellow other capabilities)

		SWARMs	MANTIS	semi40	Delphi4LED	SCOTT	I-MECH	Productive 4.0	iDev40	afarcloud	MADEin4	Arrowhead Tools
		swarms.eu	mantis-project.eu	semi40.eu	delphi4led.org	scottproject.eu	i-mech.eu	productive40.eu	idev40.eu	afarcloud.eu		https://www.arrowhead.eu/arrowheadtools
Essential Capabilities	***Systems and Components, Architecture, Design, and Integration***	green	green	yellow	green	yellow	green	green	yellow	green		green
	Connectivity and Interoperability	green	green	yellow		green	green	green	yellow	green		green
	Safety, Security, and Reliability		yellow	yellow	green	green		yellow	yellow			yellow
	Computing and Storage		yellow									
	Process Technology, Equipment, Materials, and Manufacturing for ECS			green	green			yellow	green		green	

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4.3.3 Regarding the challenges identified for the Digital Industry

SWARMS addresses mainly **MC 4,** as the approach is to design and develop an integrated platform (a set of Software/Hardware components), incorporated into the current generation of underwater vehicles in order to improve autonomy, cooperation, robustness, cost-effectiveness, and reliability of the offshore operations. And also **MC 2** as SWARMs applies IA for several purposes: An intelligent environment recognition and sensing system, an innovative perception and decision-making system and an advanced decision-making tele-operation assistance tool

MANTIS addresses **MC 3** as the main *goal of the project*. MANTIS also addresses **MC 2** as it uses AI and machine learning for wear detection (anomaly detection), root cause analysis, remaining useful life estimation and maintenance plan optimization. MANTIS also addresses **MC 4**, as the reference Maintenance Architecture can be implemented as maintenance digital platforms. In the project platforms were implemented for each use case.

SemI40 addresses **MC 1** as some of the project's main objectives included virtualization of large nonlinear fab environment; Set-up simplified models for complex dynamic and nonlinear fab simulation.' **MC 2** is also addressed in SemI40, as some of the project's objectives include 'provide Big Data in semiconductor industry with semantics- and ontology- technologies; set up a reliable data for automated decision in manufacturing processes'.

Delphi4LED addresses mainly **MC 1:** Digital twin of LED component consisting electrical-optical-thermal characteristics created. Utilizing the digital twin of a component, it is possible to simulate a module-device-system manufacturing chain. In addition, created thermal models enable component lifetime prediction modelling using a component in various product structures and environmental conditions. Delphi4LED also partially addresses **MC 3** as sensing of ambient conditions in operation for a device/system in use, such as temperature, is required to predict pre-damage warning for the device/system.

SCOTT addresses mainly **MC 4** with Architecture and ontologies for connecting networks of sensors and systems; Connection to cloud, infrastructure and user Interface. In specific use cases such as in the railway domain, digital twins and condition monitoring related results have been developed also.

I-MECH mainly addresses **MC 4** with the I-MECH platform consisting of modular building blocks. I-MECH also addresses **MC 1** due to the development of techniques for employment of advanced model-based methods for the design, real-time control and self-diagnosis of cyber-physical systems. **MC 3** is also addressed in I-MECH, due to the preparation of interfaces to a state of the art predictive maintenance platform and development of specific condition monitoring building block providing relevant data for system behaviour.

Productive 4.0 addresses **MC 1** as it has the objective 4: Development of complex simulation models for DP, SCN, PLM and the objective 5: Powerful systems for planning, virtualising, operating and controlling. Productive 4.0 also addresses **MC 2** in addressing objective 2: Data analytics framework and secure communication environment. The approach is to set up a distributed data analytics service in order to handle big data in real-time. This framework service will take advantage of machine

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learning technologies reaching TRL 8. **MC 4** is also one of the main challenges addressed in Objective 1: SoS-based architecture platform for the Digital Industry and in Objective 7: The Productive4.0 Framework as a cross-domain platform for the Digital Industry. The Productive4.0 Framework will be deployed in order to provide the industry with new platforms increasing the efficiency of the value chain and finally the product attractiveness. The platforms will enable a consistent monitoring of various target dimensions such as performance, costs or reliability over the entire product lifecycle and allow for simultaneous cost engineering. They will also target complete digitisation by integrating the existing data backbone. With the Productive4.0 Framework, reference architecture solutions will be provided for DP, SCN and PLM.

iDev40 addresses **MC 1** as project results indicate that digital twin technology will be used in demonstrators, and other visualisation tools used to do multi-factory planning and look at different concepts for the semiconductor industry. **MC 4** is addressed, as the iDev40 project description on website states iDev works on 'technologies include data centred learning approaches, cyber physical system based platforms connecting production processes from different sites… Linking the digital and the real world with new Industry 4.0 technologies'

AFarCloud addresses mainly **MC 4** as a manufacturer-independent platform for farming is developed; An interface for sensors is developed and Sensors are integrated in the platform. AFarCloud also addresses **MC 2** as sensor prediction models are developed with machine learning. And **MC 3** is covered as the project aims at improving situational awareness in farms.

MADEIn4 addresses **MC 1** as MADEin4 will focus on developing advanced and highly connected cyber physical systems using a novel Industry 4.0 approach that combines metrology data analysis and design with machine learning methodologies and digital twinning. **MC2** is also addressed in MADEIn4, as they will develop a predictive yield system in the manufacturing lines, using machine learning techniques. And **MC 3** is also covered, as CPS development which combines Machine Learning (ML) of design (EDA) and metrology data for predictive diagnostics of the process and tools performances (predictive yield and tools performance).

In Arrowhead Tools, **MC 4** is definitely the focus of the project: Provision of a mature service integration platform providing extensive interoperability between IoT services and legacy technology together with management capabilities for dynamic configuration and orchestration of System of Systems solutions. **MC 1** is addressed in some Arrowhead Tool uses cases such as the "Digital twins and structural monitoring" use case. And **MC 2** is covered, as AI is used for interoperability and in many use cases.

The main challenges of Digital Industry chapter addressed in the project are summarized in the Table 3. MC 4 is mainly addressed by 8 projects, MC 1 by 6 projects, MC 2 by 6 projects and MC 3 by 4 projects.

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Table 3: Mapping of projects regarding Major Challenges (MC) of Digital Industry in [1] (in green main challenges, in yellow partially addressed challenges)

		SWARMs	MANTIS	semi40	Delphi4LED	SCOTT	I-MECH	Productive 4.0	iDev40	afarcloud	MADEin4	Arrowhead Tools
		swarms.eu	mantis-project.eu	semi40.eu	delphi4led.org	scottproject.eu	i-mech.eu	productive40.eu	idev40.eu	afarcloud.eu		https://www.arrowhead.eu/arrowheadtools
Challenges of Digital Industry	MC1: Developing digital twins, simulation models for the evaluation of industrial assets at all factory levels and over system or product life cycles.			[green]	[green]		[green]	[green]	[green]		[green]	[yellow]
	MC2: Implementing AI and machine learning to detect anomalies or similarities and to optimize parameters.	[green]	[green]	[green]				[green]		[green]	[green]	[yellow]
	MC3: Generalizing condition monitoring, to pre-damage warning online decision-making support.		[green]		[yellow]		[green]			[green]	[green]	
	MC4: Developing digital platforms, application development frameworks that integrate sensors and systems.	[green]	[green]			[green]	[green]	[green]	[green]	[green]		[green]

ECSEL Joint Undertaking

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4.4 Conclusions of the mapping

Regarding the application areas, all the projects covers **Digital Industry** area (as expected). And there are projects such as SCOTT that are more transversal and can be used in several areas.

Regarding essential capabilities, **Computing and Storage** is not addressed by any project as main capability. And **Safety, security and Reliability** is only addressed in 2 projects as main capability.

Regarding the main challenges of Digital Industry chapter addressed in the projects, the **MC 4** is the most addressed one, followed by **MC 1** and **MC 2**. **MC 3** is the challenge covered by the least projects.

5 Conclusions

This deliverable presents the results of the mapping and analysis process performed. Firstly, this deliverable presents an analysis of relevant roadmaps in order to identify emerging topics and possible gaps. Secondly, this deliverable presents an analysis of the ECSEL projects in the Industry4.E Lighthouse in order to know about the application areas, the essential capabilities and the Digital industry challenges that are mainly addressed.

The analysis of relevant roadmaps has allowed the identification of emerging themes, during the "Task 1.2 Identification of gaps and emerging themes". The projects and project results have been analysed to see if they cover those emerging themes. Moreover, the results have been used as inputs in the writing of the Digital Industry chapter of the ECS Strategic Research Agenda 2020.

The analysed Industry 4.E Lighthouse projects present several complementarities and synergies. Some of the projects are transversal and their results could be applicable in many areas (not only digital industry). For this reason, these projects are complementary with other projects; as their results could be reused or integrated in the solutions being developed. This is the case of SCOTT and its building blocks for trust connection of devices and the case of I-MECH and its motion control building blocks. Arrowhead tools can also provide tools for Engineering of Digitalisation Solutions. MANTIS is oriented to develop a maintenance framework; its reference architecture and framework are applicable in any domain where maintenance is relevant.

Other projects are applicable in very specific vertical domains such as Delphi4LED for LED products. SWARMS is applicable to underwater vehicles. AFarCloud is oriented to digital farming, a special case of Digital Industry. However, the resultant product and systems could be applicable in more domains. And these projects can have synergies with other projects in order to reuse building blocks or share knowledge.

SemI40, iDev40 and MADEIn4 are mainly oriented towards the semiconductor industry and they could be complementary. MADEIn4 is focused in metrology, SemI40 focuses on manufacturing and production (data safety and security, agility, big data for decision making, virtualization, etc.) and IDev40 focuses on integrating processes within a digital value chain (seamlessly integrated ECS development processes, safe and secure digital automation workflows, interoperable and inter-

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organisational network solutions, enhanced transparency of data and intelligence) with a human-centric approach.

Productive 4.0 is the broadest project and it is developing solutions for several application areas, including semiconductor industry. This project could have synergies with almost all the projects of the Industry4.E Lighthouse.

Regarding the essential capabilities, **System and Components: Architecture, Design and Integration** and **Connectivity and interoperability** are the most covered capabilities. As they are the capabilities that most can help to tackle the challenges of Digital Industry such as MC 4. **Process Technology, Equipment, Materials and Manufacturing for ECS** is the main capability in 4 projects (mainly those projects oriented to semiconductor industry).

Safety, security and Reliability is the main capability in 2 projects. **Computing and Storage** is not addressed extensively. Probably because these capabilities are very relevant for the developing of ECS and Cyber physical systems but not so relevant when developing solutions for Digital Industry as the focus is on higher-level systems. However, safety, security and reliability issues are still very relevant but not the main topic of the project.

Regarding the challenges, the **MC4**: "Developing digital platforms, application development frameworks that integrate sensors and systems" is the most addressed challenge so we can conclude that platforms are quite well covered. However, each project is addressing the digital platforms that needs for their main objective: for maintenance in MANTIS project, for farming in AFarCloud, for underwater vehicles in SWARMS, etc. Even if they have been developed for a different purpose, synergies could be found between the platforms. However, the interoperability of different platforms in not so well covered. Arrowhead tools is addressing the interoperability between different digital platforms.

MC 1 "Developing digital twins, simulation models for the evaluation of industrial assets at all factory levels and over system or product life cycles" and **MC 2** "Implementing AI and machine learning to detect anomalies or similarities and to optimize parameters" are both quite popular. Virtualization approaches are being developed in different projects. As in the case of Digital Platforms, the focus of these approaches could be very different: In MC 1, Virtualization of fab environment and fab simulation (SemI40), digital twin of LED components (Delphi4LED), digital twinning for metrology (MADEIn4), etc. In MC 2, AI for predictive maintenance (MANTIS), AI for sensing, etc. (SWARMs), AI for decision making in semiconductor manufacturing (SemI40), AI for farming (AFarCloud), etc.

MC 3 "Generalizing condition monitoring, to pre-damage warning online decision-making support" is the challenge covered by the least number of projects. This could be explained due to this challenge being more specific than the other major challenges.

6 References

[1] ECSEL, ECS SRA 2019, "Strategic Research Agenda for Electronic Components & Systems 2019", January 2019, https://www.ecsel.eu/sites/default/files/2019-02/ECS-SRA%202019%20FINAL.pdf

[2] Morteza Ghobakhloo, "The future of manufacturing industry: a strategic roadmap toward

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7 Versions

D1.1 Report on programmes and project's complementarities and synergies	
Version - Date	**Comments & Recommendations**
V1 Intermediate – 01.02.2019	D1.1 initial version with table of content
V2 Intermediate – 08.02.2019	D1.1 draft version with initial content in sections 2 and 3
V3 Intermediate – 18.02.2019	D1.1 draft version with more detail about categories to use in the roadmap analysis
V4 Intermediate – 01.03.2019	D1.1 draft version with roadmaps analysis
V5 Intermediate – 14.03.2019	D1.1 consolidated version of intermediate version
V1 Final – 23.09.2019	D1.1 final version with project mapping inputs included
V2 Final version – 27.09.2019	D1.1 final complete version
V3 Final version – 30.09.2019	D1.1 final version with internal review changes
V4 Final version – 30.09.2019	D1.1 final version with all internal review changes – ready for upload

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8 Annex: Summary of lighthouse Industry 4.E projects

8.1 Mantis: Cyber Physical System based Proactive Collaborative Maintenance

General data:

- Start date: May 2015
- Project duration (months): 36
- Total investment: €29.98 M
- Number of participating organizations: 47
- Number of countries: 9
- Coordinator: Urko Zurutuza, Mondragon Goi Eskola Politeknikoa, Spain
- Web: http://www.mantis-project.eu/

Summary:

The project will develop a Proactive Maintenance Service Platform Architecture based on Cyber Physical Systems that enable "Collaborative Maintenance Ecosystems". MANTIS will contribute to improving companies' asset availability, and therefore their competitiveness, growth and sustainability by a number of relevant developments, such as reduction of the impact of maintenance on productivity and costs, improvement of the quality of the maintenance service and therefore of products, increase of sustainability by preventing material loss and reworking, and many others. The scope of technical innovation developed by MANTIS will include, among others, smart sensors, actuators and cyber physical systems capable of local pre-processing, as well as robust communication systems for harsh environments. Objectives:

- Reduce the adverse impact of maintenance on productivity and costs
- Increase the availability of assets
- Reduce time required for maintenance tasks
- Improve the quality of the maintenance service and products
- Improve labour working conditions and maintenance performance
- Increase sustainability by preventing material loss (due to out-of-tolerance production)

Technologies:

- New sensing CPS to capture maintenance relevant/critical information
- Virtual Plug & Play
    - Easy to configure and deploy complex maintenance services
- Secure wireless solutions
    - Increasing the possibility to reach inaccessible places for a wired
- Remote access that facilitate access to new geographic markets network

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- Distributed (local) decision making
- Connection to the Cloud enabling new capabilities for data aggregation and complex computing
- Distributed Big Data analysis with focus on critical data sources

8.2 SWARMs: Smart and Networking Underwater Robots in Cooperation Meshes

General data:

- Start date: July 2015
- Project duration (months): 36
- Total investment: €17.3 M
- Number of participating organizations: 30
- Number of countries: 10
- Coordinator: José-Fernán Martínez (UPM), Spain
- Web: http://swarms.eu/

Summary:

The primary goal of the SWARMs project is to expand the use of underwater and surface vehicles (AUVs, ROVs, USVs) to facilitate the conception, planning and execution of maritime and offshore operations and missions. This will reduce the operational costs, increase the safety of tasks and of involved individuals, and expand the offshore sector.
SWARMs project aims to make AUVs, ROVs and USVs further accessible and useful, making autonomous maritime and offshore operations a viable option for new and existent industries:

- Enabling AUVs/ROVs to work in a cooperative mesh thus opening up new applications and ensuring re-usability by promoting heterogeneous standard vehicles that can combine their capabilities, in detriment of further costly specialised vehicles.
- Increasing the autonomy of AUVs/USVs and improving the usability of ROVs for the execution of simple and complex tasks, contributing to mission operations' sophistication.

The general approach is to design and develop an integrated platform for a new generation of autonomous maritime and underwater operations, as a set of software/hardware components, adopted and incorporated into the current generation of maritime and underwater vehicles in order to improve autonomy, robustness, cost-effectiveness, and reliability of offshore operations, namely through vehicles cooperation.
SWARMs' achievements will be demonstrated in three field testing sites and occasions, taking into account different scenarios and use cases:

- Corrosion prevention in offshore installations
- Monitoring of chemical pollution
- Detection, inspection and tracking of plumes

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- Berm building
- Seabed Mapping

SWARMs entrusts the platform with creating, monitoring, controlling and managing the mission; to (re)distribute, (re)configure, (re)synchronize and (re)plan the activities autonomously in real-time. SWARMs technical approach considers and targets:

- A distributed, integrated and coordinated set of SW/HW components that enable AUVs/ROVs, from different manufactures, to share (integrate) functionalities (robot features) in a transparent way
- A distributed set of intelligent components for perception, decision-making and environment recognition capable of assisting the vehicles in characterizing the working environment, including artefacts
- Improved communication technologies as a base of cooperation and information exchange among vehicles, as well as the sensing (vision and acoustic) technologies
- Enhanced control and management services, and hardware, to assist in the execution of mission's tasks, entrusting SWARMs platform with creating, monitoring, controlling and managing the mission's activities autonomously in real-time

8.3 SemI40: Power Semiconductor and Electronics Manufacturing 4.0

General data:

- Start date: May 2016
- Project duration (months): 36
- Total investment: €12.23 M
- Number of participating organizations: 37
- Number of countries: 5
- Coordinator: Cristina De Luca, Infineon Technologies Austria AG, Austria
- Web: http://www.semi40.eu/

Summary:

By advancing European electronic components and systems manufacturing to "Smart Sustainable and Integrated Production", Semi40 focus on two domains of key enabling technologies, "production" and "semiconductor technologies" made in Europe.

The implementation of Industry 4.0 technologies is the key aspect of SemI40 project, to enhance sustainable competitiveness in European electronics and semiconductor production, adopting recent innovations in electronic systems and ICT technologies. SemI40 particularly concentrates on developing essential manufacturing capabilities. A well-focused approach of automation and smart production system integration in the domains of technologies, tools and methodologies, which are complemented by innovations in the area of secure communication, knowledge management,

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automated decision-making and smart agile production execution, will ensure the competitive production in Europe.

Balancing of system security and production flexibility

Objective 1: Provide reference demonstrator solutions for increased safety and robustness against cyber-attacks in vintage production environment

Increased information transparency between fields and enterprise resource planning (ERP)

Objective 2: Provide Big Data in semiconductor industry with semantics- and ontology- technologies. Set up a reliable data for automated decision in manufacturing processes

Management of critical knowledge decision making and for maintenance

Objective 3: Achieve better data quality from sensors and measurement instruments and methods to identify untrusted data. Automated decision making based on knowledge and rules.

Fab digitalization and virtualization incl. simulation platform

Objective 4: Virtualization of large nonlinear fab environment. Set-up simplified models for complex dynamic and nonlinear fab simulation.

Automation systems for flexible distributed production

Objective 5: Enable economically optimized production of small lot size and implement full single wafer traceability across multiple productions sites.

Power Semiconductor and Electronics Manufacturing 4.0 focusses on four highly challenging aspects of utmost importance:

- Data Safety and security in manufacturing environment with special attention on legacy equipment
- Agility in ECS production for fast adaptability to changes
- Tools and methodologies for automated decision making in manufacturing shop floor, based on big data analysis methods
- Virtualization and digitalization for advanced simulation in fab environment

These aspects are thematically grouped and clearly structured by work tasks and correspondingly organized into 5 closely interacting work packages, supported by 2 strategic work packages.

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8.4 Delphi4LED: From Measurements to Standardized Multi-Domain Compact Models of LEDs

General data:

- Start date: June 2016
- Project duration (months): 36
- Total investment: €2.7 M
- Number of participating organizations: 15
- Number of countries: 7
- Coordinator: Genevieve Martin, Philips Lighting B.V.
- Web: https://delphi4led.org/

Summary:

The main objective of Delphi4LED is to develop a standardized method to create multi-domain (thermal-optical-electrical) LED based design and simulation tools for the solid-state lighting industry.

Tools and standards will be developed on various levels to enable the design and manufacturing of more reliable and cost-effective LED based lighting solutions which can be brought to the market much faster than today. The availability of these standards and tools will also boost the market of integrated smart lighting solutions and by that give Europe the opportunity to outpace the global competition.

8.5 Productive 4.0: Electronics and ICT as enabler for digital industry and optimized supply chain management covering the entire product lifecycle

General data:

- Start date: May 2017
- Project duration (months): 36
- Total investment: €25.88 M
- Number of participating organizations: 108
- Number of countries: 16
- Coordinator: Knut Hufeld, Infineon Technologies AG, Germany
- Web: http://productive40.eu/

Summary:

The aim is to create a user platform across value chains and industries, thus promoting the digital networking of manufacturing companies, production machines and products.

The participating partners will examine methods, concepts and technologies for service-oriented architecture as well as for components and infrastructure in the Internet of Things. Other aspects are standardization and process virtualization, in other words, simulating manufacturing processes to

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optimize real workflows. The platform can be used in the three interlocked process pillars for managing the supply chains, the product life cycle and digital production.

The main objective of Productive4.0 is to achieve improvement of digitalizing the European industry by electronics and ICT.

Ultimately, the project aims at suitability for everyday application across all industrial sectors – up to TRL8. It addresses various industrial domains with one and the same approach of digitalization. What makes the project unique is the holistic system approach of consistently focusing on the three main pillars: digital production (DP), supply chain networks (SNC) and product lifecycle management (PLM), all of which interact and influence each other.

This is part of the new concept of introducing seamless automation and network solutions as well as enhancing the transparency of data, their consistence and overall efficiency. Currently, such a complex project can only be realized in ECSEL. The consortium consists of 45% AENEAS, 30% ARTEMIS-IA and 25% EPOSS partners, thus bringing together all ECSEL communities.

Productive4.0 will furnish companies with fundamental tools necessary for the digital transformation. It focuses on a digitalized production applicable to all kinds of products. The results such as IoT components modelling and simulation methods as well as tool chains for cross-lifecycle and cross-domain digitalization are suitable means for linking all stages of a product lifecycle in a sustainable way. The project consists of 10 work packages (WPs), each with individual technical objectives.

Furnish the industry with SoS-based system architecture platforms supporting automation and digitalization for a sustainable production

SoS-based means the collection of dedicated systems in order to pool their capabilities for generating new and overall efficient complex systems. They will provide a domain independent platform enhancing automation and digitalization, application development, deployment, operation and maintenance. Covering fields like seamless integration of design, manufacturing and lifecycle management, this platform will boost overall efficiency.

The key platform requirements are real-time performance, safety and security, engineering and scalability as well as support of plant capturing, of device and system configuration and of production associated to business models and transactions support. The platform core design and implementation are targeting TRL 7-8. Digital production, Supply Chain Networks and Product Lifecycle Management support the platform's functionalities. Designs and implementations are targeting TRL 5-7.

8.6 SCOTT: Secure Connected Trustable Things

General data:

- Start date: May 2017
- Project duration (months): 36

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- Total investment: €10.23 M
- Number of participating organizations: 57
- Number of countries: 11
- Coordinator: Michael Karner, Komp.zentrum-Das virtuelle Fahrzeug Forsch.gesellschaft mbH, Austria
- http://scottproject.eu/

Summary:

Creating trust in wireless solutions and increasing their social acceptance are major challenges to achieve the full potential of the Internet of Things (IoT). Therefore, SCOTT – Secure COnnected Trustable Things, a pan-European effort with 57 key partners from 12 countries (EU and Brazil), will provide comprehensive cost-efficient solutions of wireless, end-to-end secure, trustworthy connectivity and interoperability (Technology Readiness Level 6-7) to bridge the last mile to market implementation. SCOTT will not just deal with ‚things that are connected‘, but with ‚trustable things that securely communicate‘, i.e. things interconnected by dependable wireless technology and valuing the end-users‘ privacy rules.

SCOTT uses a standardized multi-domain reference architecture, created in a predecessor project (DEWI and its “Bubble concept”) and being fully compliant with ISO 29182 – Sensor Network Reference Architecture, which fosters reusability, scalability, and interoperability of SCOTT solutions. SCOTT also utilizes a clearly use-case driven approach with 15 use cases from different areas of high relevance to European society and industry; a specific focus will be put on cross-domain use cases and heterogeneous environments, emphasizing 5G and cloud computing aspects to build up digital ecosystems to achieve a broader market penetration.

Tangible results from all use cases will ultimately be shown to a broader public via more than 20 demonstrators all over Europe.

Use Cases will be further substantiated by the development and utilization of nearly 50 technical building blocks for security/safety, distributed cloud integration, energy efficiency/autonomy of devices and reference architecture/implementations, which are all necessary to realize the SCOTT use cases and facilitate composability of systems as well as cross-domain sharing of trustable wireless technologies and services.

The excellent partner consortium of SCOTT facilitates comprehensive vertical integration in different areas, covering the full value chain from silicon to end-users and operators. By providing reference implementations, SCOTT aims at establishing an eco-system for trustable wireless solutions and services for both professional and private users by attracting 3rd parties and particularly SMEs. This together with the involvement of open innovation approaches and stakeholder engagement as well as close cooperation with AIOTI, the Alliance for Internet of Things Innovation, and other cluster organizations all over Europe will further boost and exploit the growing “Internet economy”.

SCOTT will open up new market opportunities for the European industry, will significantly reduce time to market and decrease costs for trustable wireless solutions on the market, in particular by using new

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designs and technical building blocks. SCOTT will develop methods and tools capable of meeting prospect use-case requirements on reliability, robustness, security and functional safety even in harsh and/or not trusted environments.

Ultimately, SCOTT will foster the European leadership for Smart and Connected Things (including Internet of Things) and will strengthen Europe's independence for security enabling components and systems.

SCOTT aims to extend the Internet of Things:

- for wirelessly connected
- smart sensors and actuators
- to be used in building & home / smart infrastructure, mobility, health domains
- ensuring safety and security, privacy and trustability

Key solutions in SCOTT will be developed:

- by using an eco-system with re-usable building blocks
- targeting higher Technology Readiness Levels (TRL 6-7)
- aiming at strengthening European leadership and market opportunities.

8.7 I-MECH: Intelligent Motion Control Platform for Smart Mechatronic Systems

General data:

- Start date: June 2017
- Project duration (months): 36
- Total investment: €17 M
- Number of participating organizations: 31
- Number of countries: 10
- Coordinator: Arend-Jan Beltman, SIOUX CCM B.V.
- https://www.i-mech.eu/

Summary:

The broad I-MECH challenge is to bridge the gap between the latest research results and best industrial practice in advanced mechatronic motion control systems. Software and Hardware building blocks, featuring standardized interfaces, will be developed to deliver a complete **I-MECH reference platform**.

The Key Scientific and Technical objectives are:

- To develop techniques for employment of advanced model-based methods for the design, real-time control and self-diagnosis of cyber-physical systems

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- To develop a smart Instrumentation Layer gathering visual and/or sensor information from supplementary instrumentation installed on the moving parts of the controlled system to enhance the achievable performance of the system
- To develop modular unified, Hardware and Software motion control building blocks implementing a service-oriented architecture paradigm, i.e. smart Control Layer

To make I-MECH sustainable, the project outcomes will be available for European industry also through the envisioned **I-MECH Centre**, after completion of the project.

I-MECH will significantly strengthen European industrial competitiveness through the design and implementation of improved mechatronic smart systems. I-MECH will lead to improved machine performance and reliability as measured by a whole variety of parameters including response time, reliability, control bandwidth, control accuracy and error. Furthermore, the model-based approach will produce an expected 50% reduction in development time for control (sub) systems for mechatronic applications. The project outputs will impact on the entire value chain of the production automation market. The high added value of I-MECH reference platform will be directly verified in the fields of

- high-speed/big CNC machining
- additive manufacturing
- semicon
- high-speed packaging
- healthcare robotics

8.8 AFarCloud: Aggregate Farming in the Cloud

General data:

- Start date: Jan 2018
- Project duration (months): 36
- Total investment: €16.6 M
- Number of participating organizations: 59
- Number of countries: 14
- Coordinator: José-Fernán Martínez-Ortega, Universidad Politécnica de Madrid, Spain
- Web: http://grys.upm.es/afarcloud/

Summary:

Farming is facing many economic challenges in terms of productivity and cost-effectiveness, as well as an increasing labour shortage partly due to depopulation of rural areas. Reliable detection, accurate identification and proper quantification of pathogens affecting both plant and animal health, must be kept under control to reduce unnecessary costs, trade disruptions and even human health risks.

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AFarCloud addresses the urgent need for a holistic and systematic approach. It will provide a distributed platform for autonomous farming, which will allow the integration and cooperation of Cyber Physical Systems in real-time for increased agriculture efficiency, productivity, animal health, food quality and reduced farm labour costs. This platform will be integrated with farm management software and will support monitoring and decision-making, based on big data and real time data mining techniques.

AFarCloud also aims to make farming robots accessible to more users by enabling farming vehicles to work in a cooperative mesh, opening up new applications and ensuring re-usability, as various standard vehicles can combine their capabilities in order to boost farming efficiency.

The achievements from AFarCloud will be showcased in early laboratory trials and holistic demonstrators, including cropping and livestock management scenarios. Local demonstrators will test specific functionalities and validate project results in relevant environments located in different European regions.

AFarCloud outcomes will strengthen partners' market position, boosting their innovation capacity and addressing industrial needs both at EU and international levels. The consortium represents the whole ICT-based farming solutions' value chain, including all key actors needed for the development, demonstration and future market uptake of the precision farming framework targeted in the project.

8.9 iDev40: Integrated Development 4.0

General data:

- Start date: May 2018
- Project duration (months): 36
- Total investment: €47.2 M
- Number of participating organizations: 38
- Number of countries: 6
- Coordinator: Johann Massoner, Infineon Technologies Austria AG, Austria
- Web: http://www.idev40.eu/

Summary:

The ongoing digital transformation of the European industry will create enormous opportunities for business and society. Researchers and business leaders recognize the role of digital technology, which is shifting from supporting processes towards becoming the enabler of fundamental business innovation and disruption.

However, companies aiming to benefit from digitization will have to radically re-think not only how they can apply digital technology, but moreover on how they can increase their level of digital maturity to better integrate their processes – most notably development and production – within a future digital value chain.

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iDev40 introduces seamlessly integrated ECS development processes, safe and secure digital automation workflows, interoperable and inter-organizational network solutions as well as an enhanced transparency of data and intelligence that will lead to a reduction in the time to market (T2M) race for ECS solutions. This project will take the human factor seriously throughout all planned industrial use cases and will increase people excellence by identifying human-centric complexity drivers for integrated development and production, defining the right skill profiles of the employee in the factory of the future to cope with digitalization challenges and thereby scale digital technology adoption.

Concerning the impact beyond the ECS industry itself, it is obvious that competitiveness of key European industrial domains heavily depends on the availability of leading edge ECS. 80% to 90% of the key differentiating competitive features of e.g. leading edge industrial and mobility suppliers are dependent on the built-in electronic components and software.

Thus, the strategic goal of iDev40 is to enhance essential competencies for ECS “Made in Europe” to support in a sustainable manner European companies that have dominant global positions in key application areas such as efficient use of limited energy resources, smart mobility as well as in equipment and materials for worldwide semiconductor manufacturing.

Ultimately, iDev40 will foster European Leadership on Industry 4.0 as an important measure to safeguarding more than 15.000 jobs directly in the participating partner facilities, ~50.000 jobs of the people employed at all industry partner facilities worldwide as well as ~3Million jobs in the whole European ECS value chain.

8.10 MADEin4: Metrology Advances for Digitized ECS industry 4.0

General data:

- Start date: April 2019
- Project duration (months): 36
- Total investment: €127,5 M
- Number of participating organizations: 47
- Number of countries: 10
- Coordinator: Applied Materials Israel Ltd
- Web: Not yet

Summary:

The metrology domain (which could be considered as the ‘eyes and ears’ for both R&D&I and production) is a key enabler for productivity enhancements in many industries across the electronic components and system (ECS) value chain and have to be an integral part of any Cyber Physical Systems (CPS) which consist of metrology equipment, virtual metrology or Industrial internet of things (IIoT) sensors, edge and high-performance computing (HPC). The requirements from the metrology is to support ALL process steps toward the final product. However, for any given ECS technology, there

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is a significant trade-off between the metrology sensitivity, precision and accuracy to its productivity. MADEin4 address this deficiency by focusing on two productivity boosters which are independent from the sensitivity, precision and accuracy requirements: • Productivity booster 1: High throughput, next generation metrology and inspection tools development for the nanoelectronics industry (all nodes down to 5nm). This booster will be developed by the metrology equipment's manufacturers and demonstrated in an industry 4.0 pilot line at imec and address the ECS equipment, materials and manufacturing major challenges (MASP Chapter 15: ECS Process Technology, Equipment, Materials & Manufacturing, major challenges 1 – 3). • Productivity booster 2: CPS development which combines Machine Learning (ML) of design (EDA) and metrology data for predictive diagnostics of the process and tools performances predictive diagnostics of the process and tools performances (predictive yield and tools performance). This booster will be developed and demonstrated in an industry 4.0 pilot line at imec, for the 5nm node, by the EDA, computing and metrology partners (MASP Chapter 15, major challenge 4). The same CPS concept will be demonstrated for the 'digital industries' two major challenges of the nanoelectronics (all nodes down to 5nm) and automotive end user's partners (MASP Chapter 9: Digital Industry, major challenges 1 and 3).

8.11 Arrowhead Tools: Arrowhead Tools for Engineering of Digitalisation Solutions

General data:

- Start date: May 2019
- Project duration (months): 39
- Total investment: €90.7 M
- Number of participating organizations: 81
- Number of countries: 18
- Coordinator: Jerker Delsing (Lulea Tekniska Universitet)
- Web: https://arrowhead.eu/arrowheadtools

Summary:

For the purpose of creating digitalisation and automation solutions Arrowhead Tools addresses engineering methodologies and suitable integrated tool chains. With the global aim of substantial reduction of the engineering costs for digitalisation/automation solutions. Thus, the Arrowhead Tools vision is: - Engineering processes and tool chains for cost efficient developments of digitalization, connectivity and automation systems solutions in various fields of application for the further and wider commercialisation of automation and digitalisation services and products based on SOA, Arrowhead Framework and similar technologies. There is a clear need for engineering tools that integrates existing automation and digitalisation engineering procedures and tool with SOA based automation/digitalisation technology. For this purpose, the Arrowhead Tool's grand challenges are defined as: - Engineering costs reduction by 40-60% for a wide range of automation/digitalisation solutions. - Tools chains for digitalisation and automation engineering and management, adapted to: 1. existing automation and digitalisation engineering methodologies and tools 2. New IoT and SoS

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automation and digitalisation engineering and management tools 3. Security management tools - Training material and kits for professional engineers. The results will create impact on: - Automation and digitalisation solution market - Automation and engineering efficiency and the SSBS market - Automation and digitalisation security - Competence development on engineering of automation and digitalisation solution

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