CSA-Industry4.E

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Coordination & Support action for Lighthouse Initiative Industry4.E

Deliverable 1.2

Report on industrial digitalisation roadmap gaps identification

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Lead parties for Deliverable: S2i
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Table of Contents

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Summary

This deliverable presents the results of the gaps identified and recommendations derived from the analysis of 'Digital Industry' related roadmaps and Industry4.E Lighthouse Projects. The work that led to the deliverable was performed as part of Work Package 1 ('Enabling the execution of the Industrial digitalisation roadmap') of the CSA-Industry4.E project that is supporting the implementation of the Industry4.E Lighthouse.

The process of identifying gaps has included a roadmap and project mapping by the CSA-Industry4.E partners, a session within the Industry4.E Lighthouse Project Collaboration Meeting to identify further emerging themes, the elaboration of 'special topics' for the Electronic Components & Systems Strategic Research Agenda (ECS SRA), and the ECSEL-JU Multi Annual Strategic Plan (MASP), update in close collaboration with the ECSEL-JU and Industry4.E Lighthouse Initiative Advisory Service (LIASE), and a consultation with the Industry4.E Lighthouse Projects, ECS SRA Digital Industry chapter representatives and other experts in the field to confirm the results.

Main gaps identified included technical themes related to:

- AI enabled manufacturing in socio-technical systems with the human in the loop,
- Sustainable manufacturing in a circular economy
- Multi-technology co-engineering
- Modelling and simulation (beyond the Digital Twin)

Main gaps regarding non-technical themes were highlighted to be:

- Skills development, re-skilling training
- Business models, value creation networks
- Standardisation

These findings have been given as input and already discussed within the ECS SRA writing group for the update of the ECS SRA 2020 (to be published at EFECS 2019). The results were also evaluated in comparison to major findings from expert interviews with members of the wider Industry4.E stakeholder community. Moreover, the ECSEL-JU requested proposals for 'special topics' for an update of the ECSEL-JU MASP, where the above themes were proposed and the 'AI enabled manufacturing with the human in the loop' was selected.

Furthermore, the results of this CSA-Industry4.E Deliverable will also feed into the D1.3, where more detailed recommendations for updates of the next ECS SRA will be elaborated.

Team involved in deliverable writing: S2i, MGEP, VTT

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1 Introduction and Context

For the identification of 'potential gaps and emerging themes' for the ECS SRA 'Digital Industry' chapter, it is important to not only define the 'scope of the ECS SRA and this specific chapter', but also to identify differences, complementarities and synergies of the different programs and roadmaps to finally decide which themes to include in the future ECSEL-JU MASP. Currently, an extensive ecosystem of programs, PPPs, technology or application sector specific initiatives exists, in which ECSEL plays a pivotal role, with its focus on 'electronic components and systems' for a wide area of digital industries including discrete manufacturing, process industries, robotics but also agriculture and food industries.

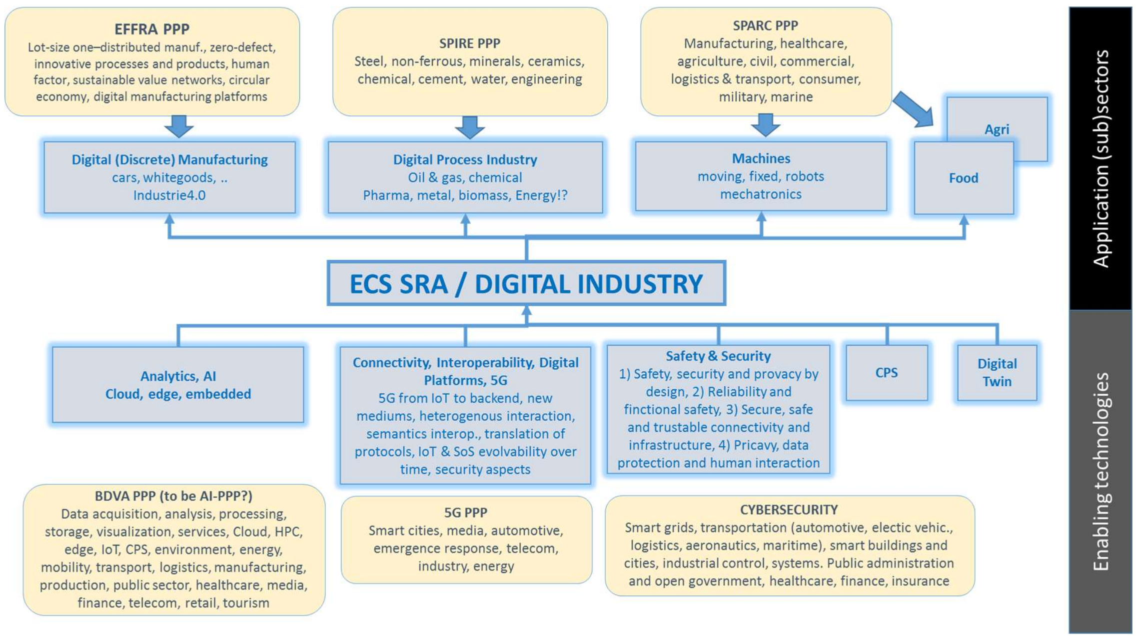

Figure 1: The Digital Industry Ecosystem

The current ECS SRA Chapter on 'Digital Industry' has put its focus on the following four major challenges, which are assessed to be still valid (CSA-Industry4.E D1.1 and D1.2 at hand), but should be refined and extended with new topics along with technological evolution and identification of new trends and emerging themes. The current 'major challenges' of the 2019 'Digital Industry' Chapter are:

- **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 optimise parameters'
- **Major challenge 3:** 'Generalising condition monitoring, to pre-damage warning on-line decision-making support and standardisation of communication scenarii to enable big data collection across huge (remote) sites'
- **Major challenge 4:** 'Developing digital platforms, application development frameworks that integrate sensors/actuators and systems'

This deliverable identifies emerging themes and gaps for possible refinements, which in D1.3 will be formulated as recommendations for the upcoming digitisation roadmap.

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2 Approach

The Deliverable 1.2 presents the identification of gaps based on the analysis of a selection of 'Digital Industry' related roadmaps and results from the CSA-Industry4.E project mapping in D1.1, as well as the derivation of preliminary recommendations for updates of the 'Digital Industry Chapter' of the ECS SRA (and ECSEL-JU MASP).

Deliverable D1.2 summarises the outcomes of CSA-Industry4.E Task 1.2 '**Identification of gaps and emerging themes**'. It builds upon D1.1, which has performed a mapping of the Industry4.E Lighthouse Projects, and will feed into D1.3, which will put forward the recommendations for updates regarding the 'Digital Industry Chapter' within the ECS SRA. The approach for the identification of gaps and emerging themes has been based on comparing visions as well as emerging research & innovation priorities of the following roadmaps (which had been selected during the development of D1.1):

- EFFRA Roadmaps + Factories of the Future in Horizon Europe (2021-2027) (2019)
- Manufuture Vision 2030 (2019)
- World manufacturing forum report (2018)
- CPS Roadmaps (Platforms4CPS, Road2CPS and CPSoS) (2018)
- European Roadmap for Industrial Process Automation, 2nd version (2018)
- Eureka Smart Advanced manufacturing Technology Roadmap (2018)
- Big data: European Big Data Value Strategic Research and Innovation Agenda, BDVA, 2017 +
- HiPEAC Vision (2109)
- Industrie 4.0 Roadmap (national/German-2016)

Building on the analysis of projects and roadmaps in Task 1.1, areas are identified where the ECS SRA is lagging behind. This was done through filtering and comparing results and advancements from projects for specific core topics (including digital twin, AI, machine learning, digital platforms) as well as assessing the four major challenges and technical as well as non-technical cross-cutting themes against related roadmaps, foresight documents and the EFFRA/Lighthouse 4.E Innovation Portal. The deliverable at hand focusses on the analysis of gaps regarding the emerging themes, research priorities, innovation accelerators, enablers and cross-cutting themes identified.

Within this deliverable, in a first step, the identification of gaps and possible adaptions /extensions for the ECS SRA is done individually for each roadmap and each major challenge. Moreover, topics not yet addressed within the 4 major challenges are presented as additional topics. In a second step, to compare the different roadmaps, the topics addressed by each roadmap are presented in a matrix visualising the gaps. In a third step, the results of the identified areas where the current ECS SRA could be enhanced/refined were discussed with the Industry4.E LIASE, Industry4.E Lighthouse Projects and the European Commission, to feed into the recommendations for future topics of the ECS SRA chapter on 'Digital Industry' as well as 'special topic' within the upcoming ECSEL-JU MASP.

The process of identifying gaps has included a roadmap and project mapping by the CSA-Industry4.E partners, a session within an Industry4.E Lighthouse Collaboration Meeting to identify further emerging themes, the elaboration of 'special topics' for the ECSEL-JU MASP update in close collaboration with the Industry4.E LIASE and ECSEL-JU including a presentation at the Governing Board, and a consultation with the Industry4.E Lighthouse Projects, ECS SRA Digital Industry chapter representatives and other experts in the field to discuss and confirm the results.

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3 Analysis of Selected Roadmaps

3.1 EFFRA Vision for Horizon Europe (2021-2027)

Scope: The EFFRA Vision focuses on 'discrete manufacturing'. The Factory of the Future roadmap priorities include 'digital topics' as well as materials, processes, recycling and energy management.

Emerging technological themes / future research priorities / enablers:

CO-CREATION THROUGH MANUFACTURING ECO-SYSTEMS

Excellent, responsive and smart factories

- Scalable first-time right manufacturing
- Agile and robust optimal manufacturing

Low-environmental footprint, customer-driven value networks

- Demand and customer-driven manufacturing networks
- Sustainable symbiotic manufacturing networks

Parallel product and manufacturing engineering

- Integrated 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

Human-driven innovation

- Co-creation in European knowledge networks
- Human & technology complementarity
- Managing constant change

ENABLING TECHNOLOGIES AND APPROACHES

- Smart mechatronic systems, devices and components
- Simulation and modelling (digital twins) covering the material processing level up to manufacturing system, and factory and value network level
- Data analytics, artificial intelligence, machine learning and deployment of digital platforms for data management and sharing
- Intelligent and autonomous handling, robotics, assembly and logistic technologies
- Robust and secure industrial real-time communication technologies, and distributed control architectures

Innovation accelerators / Impacts

- New business and new organisational approaches, including links with regulatory aspects such as safety, data ownership, and liability

- **Competitiveness** (Performance): Improvement in productivity, quality and response-time
- **People:** Social innovations, digital skills, human-machine-relation
- **Planet:** Circular Economy, reduce resources, emissions, waste, low-footprint approaches
- **Manufacturing the Products of the Future:** Opening/creating new markets, innovation

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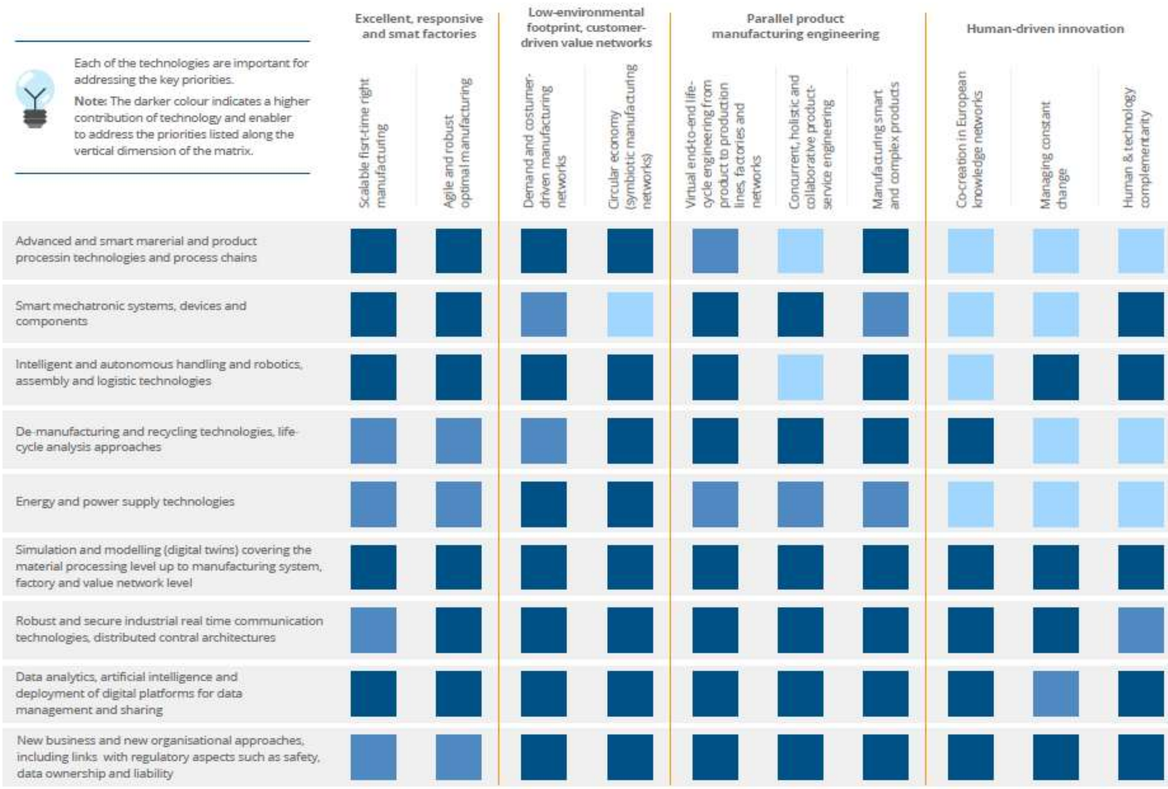

Figure 2: Matrix of technologies and enablers for Industry 4.0 (source: EFFRA Vision)

Differences / Possible Gaps:

- **Design principles:** trends to further ‘leave the factory floor’ and embrace ‘the bigger picture’ including the manufacturing eco-system and co-creation
- **Human driven innovation**
  - Human & technology complementarity
  - Reshape the human-machine-relation, smooth human AI interaction
  - Improving human device interaction using augmented, virtual reality, digital twins
  - New approaches and engineering tools supporting creativity and productivity
  - Co-creation through manufacturing ecosystems
  - Collaborative product-service engineering for costumer driven manufacturing value networks
  - Social innovation, blending social innovation and technological innovation
- **Sustainable manufacturing** and **Circular Economy:**
  - Circular, low footprint low-carbon, approaches-carbon approaches
  - Simulation and communication technologies for circular economy
  - Mastering and tracing the product and production-life-cycle in a circular system
  - De-manufacturing, re-manufacturing and recycling technologies for circular economy
- **5G** in support of smart factories in dynamic value networks, robust, secure real-time comm.
- Distributed control architectures, **distributed ledger** for industrial applications
- **Skills** related challenges, need for adequate skill sets in manufacturing, new job profiles, well-being, safety, competence and qualification growth, social and environmental responsibility

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- **Business related,** new business and organisational approaches, including links with regulatory aspects such as safety, data ownership, and liability
- **Co-creation** through **manufacturing ecosystems,** customer driven manufacturing value networks, social innovation

Preliminary Recommendations:

From the analysis of the EFFRA Roadmap, recommendations include i) the extension of existing themes and/or ii) addition of new topics

I. Proposals to adapt/extend 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 life-cycles'

Could be extended to:

- Improving human device interaction using augmented, virtual reality, digital twins
- Virtual end-to-end life-cycle engineering from product to production lines, factories, networks
- Simulation technologies for circular economy

Major Challenge 2: 'Implementing AI and machine learning to detect anomalies or similarities and to optimise parameters' and **Major challenge 3:** 'Generalising condition monitoring, to pre-damage warning on-line decision-making support and standardisation of communication scenarii to enable big data collection across huge (remote) sites'

Could be extended to:

- **Artificial intelligence** for productive, excellent, robust and agile manufacturing chains
- Scalable, reconfigurable and flexible **first-time right** manufacturing
- Predictive quality and non-destructive inspection methods for **zero-defect** manufacturing

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

II. In case new themes would be added, these could relate to:

- **Topic 1:** Human machine relation, interaction, collaboration, complementarity, human driven innovation, co-creation through manufacturing ecosystems, customer driven manufacturing value networks, social innovation
- **Topic 2:** Sustainable manufacturing in a Circular Economy

Other new innovation related topics could include:

- Human driven innovation, co-creation, managing constant change
- New business and new organisational approaches

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3.2 MANUFUTURE Vision 2030 (2018)

Scope: 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 2030 Vision addresses the need for a resilient and adaptive manufacturing ecosystem able to cope with increasing levels and environmental and social requirements.

Emerging technological themes / future research priorities:

- **Resilient factories** (flexible, AI supported); resilient and adaptive manufacturing ecosystem, lot-size-one production, zero-defect manufacturing, 'Dynamic Virtual Value Networks'
- **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 centered 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, customer-centric value creation networks
- **Platforms** for storage of sensor data and **traceability of transactions in blockchains** as well as the cyber security, including privacy protection, open platforms for collaboration

Enablers:

- Integration, standardization
- Cybersecurity
- Key enabling technologies
- Cloud- and edge-based manufacturing
- Mastering complexity of products, processes and systems

Innovation accelerators:

- Digital transformation and new business models, 'Dynamic Virtual Values Networks'
- Empowerment of customer in value creation via grids or webs, mass customisation
- Entrepreneurship, skills, and training, 'Learning/Teaching Factory Model'
- Contributions from Social Sciences and Humanities**,** law, political sciences, and ethics
- Circular economy cooperation, resource efficiency and sustainable development
- Innovation ecosystem

Differences / Possible Gaps:

- Human centred manufacturing, HUMANufacturing
- Resilient and adaptive manufacturing ecosystems, 'Dynamic Virtual Values Networks'
- (Ledger based) advanced platforms for ad-hoc collaboration enabling new business models
- Circular economy, sustainability monitoring, resource efficiency, re- and de-manufacturing
- Nature-inspired manufacturing
- Call for international standardization

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Preliminary Recommendations:

From the analysis of the Manufuture Vision 2030 Roadmap, recommendations include i) the extension of existing themes:

I. Extension of existing 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 life-cycles'

Could be extended to:

- detailed digital twins for machines, production lines and complete factories

Major Challenge 2: 'Implementing AI and machine learning to detect anomalies or similarities and to optimise parameters' and **Major challenge 3:** 'Generalising condition monitoring, to pre-damage warning on-line decision-making support and standardisation of communication scenarii to enable big data collection across huge (remote) sites'

Could be brought together as '**AI enabled/optimised manufacturing'** including / extended to:

- **AI supported resilient** manufacturing ecosystems
- Harnessing big data knowledge for global manufacturing supply networks
- AI adapted to product design, operations, decision-making, customer interaction (consumer behaviour, product utilisation) manufacturing and global supply networks
- **AI** enabling increased levels of **automation and human interaction**, supporting human activities of analysis, decision-making, and considering uncertainties
- HUMANufacturing – Human centred manufacturing, human in the loop
- Constant and continuous monitoring of the environmental change

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

Could be extended to (in MANUfuture more business related aspects):

- Advanced IT platforms to provide **business intelligence** and advanced decision-making
- Digital platforms to support product design and development, possibly including the **end consumer**, and operations management
- Platform manufacturing, engineering, logistic and service companies to **interact through interoperable systems** and **open standards** increasing agility, modularity, resilience, and flexibility, while enabling **new business models** and manufacturing strategies
- 'Dynamic Virtual Value Networks' with **platform-based ad-hoc value networks**, emerging spontaneously to match specific business opportunities at global level. Manufacturing companies and service providers offer their skills and capacities on the platform.
- Platform structures for **SMEs** that focus on efficiency and intelligence
- Digital platforms for storage of sensor data, traceability in **blockchains**, ledger based platforms

II. In case new themes would be added, these could relate to:

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- **Topic 1:** Manufacturing as networked, dynamic socio-technical systems, HUMANufacturing as a new era of automation and human interaction, customer-centric value creation networks
- **Topic 2:** Artificial Intelligence supported flexible, resilient, adaptive manufacturing ecosystem, ‘Dynamic Virtual Value Networks’
- **Topic 3:** New business models through (ad-hoc collaboration on) (ledger based) platforms
- **Topic 4:** Responsible value creation in a circular economy, sustainable manufacturing

<u>Other new innovation related topics could include:</u>

- **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, ‘Dynamic Virtual Values Networks’
- **Balanced and sustainable ecosystems** (customer centric and environmental aware, open)
- **Innovation and Entrepreneurship**
- **Skills and Training,** Learning/Teaching Factory Model, partnerships for manufacturing skills
- Contributions from **Social Sciences and Humanities,** law, political sciences, and ethics
- **Manufacturing and Society**

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3.3 The World Manufacturing Forum Report (2018)

Scope: The 2018 WMF Report examines a variety of societal megatrends (ex. demographic change, workforce diversity, urbanisation, etc.) and compares them with emerging challenges in the global manufacturing sector. It also names six major disruptive trends that are likely to share the future of manufacturing on a global scale in the long-term.

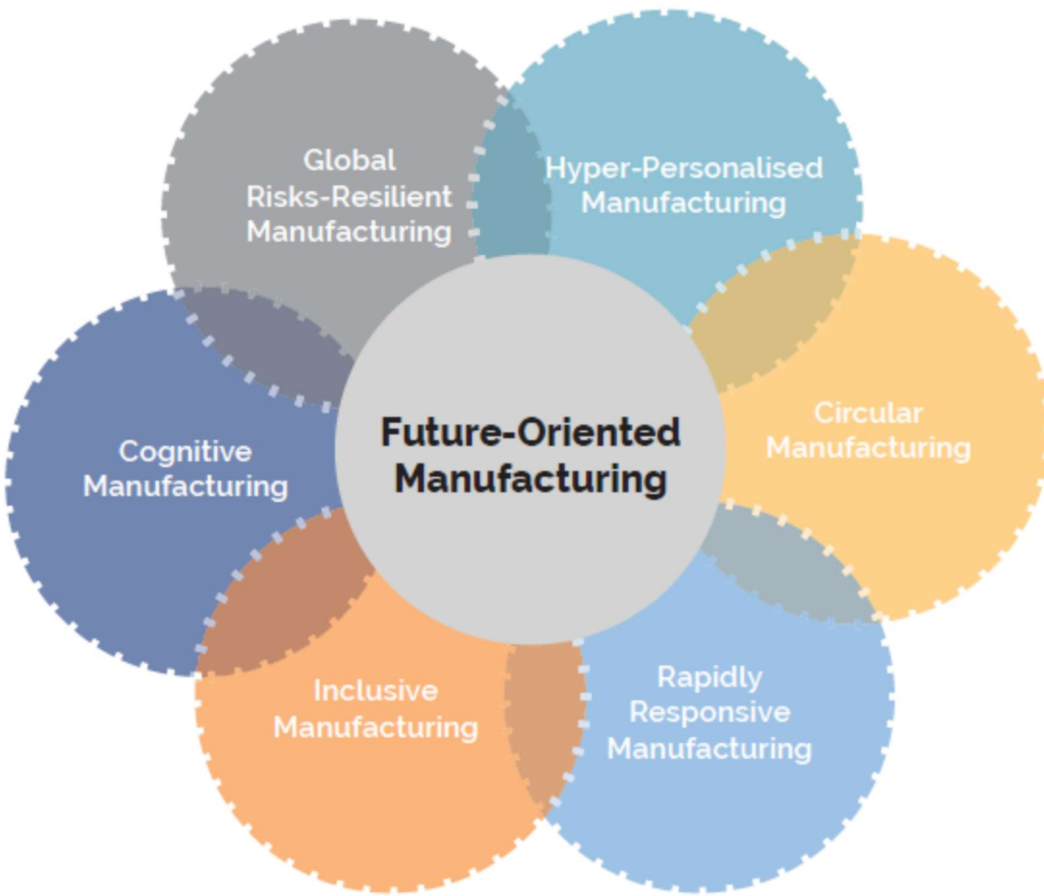

Figure 3: Future-oriented manufacturing trends (source: WMF Report)

Emerging technological themes / future research priorities:

- **Cognitive manufacturing**
    - Hyper-connected intelligent machines
    - AI-driven cognitive operations
    - Smart optimisation of resources
    - Collaborative manufacturing as a service in the cloud
- **Rapidly Responsive Manufacturing**
    - Agile, adaptive, responsive and robust manufacturing
    - Flexible production systems and supply chains
    - Digitally empowered factory operations

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- **Hyper-Personalised Manufacturing**
  - Embed sensors, direct feedback on usage, personalised products
  - 3D printing and flexible manufacturing processes to adapt rapidly to changing demands
  - Involve customers in the design of products.
- **Global Risks-Resilient Manufacturing**
  - Reinforcing cybersecurity, integrating blockchain, responding to off-shore threats
  - Exploiting social IoT systems
  - Involving all stakeholders in the digital value chain
- **Circular Manufacturing**
  - Redesign, recover, renewable and re-use
  - Implement a service-based model for circular products
- **Inclusive Manufacturing**
  - People, environment and technology-oriented Innovation

Enablers:

- Cybersecurity, data security, data authority, blockchain
- Collaborative manufacturing as a service from cloud
- Embedded sensors for direct feedback on usage to develop more personalised products
- Use 3D printing to accelerate prototyping

Innovation accelerators:

- Cultivate a positive perception of manufacturing
- Involving all stakeholders in the digital value chain
- Encourage eco-systems for manufacturing innovation world-wide
- Assist SMEs with digital transformation
- Develop effective policies to support global business initiatives
- Promote resource efficiency and country specific environmental policies
- Strengthen and expand infrastructures to enable future-oriented manufacturing
- Promote education and skills development for societal well-being
- Education and skill-building- ‘Teaching Factory’ model, ‘Know-how’ big data mastery
- Create attractive workplaces for all
- Design and produce socially-oriented products
- Explore the real value of data-driven cognitive manufacturing

Differences / Possible Gaps:

- Cognitive manufacturing (AI, smart optimisation, cloud services)
- Rapidly responsive manufacturing (flexible production, agile, and responsive)
- Hyper-personalised manufacturing (embedded sensors, flexibility, 3D printing)
- Global risks-resilient manufacturing (cybersecurity, blockchain, digital value chain)
- Circular manufacturing (renewable, reuse, service-based model for circular products)
- Inclusive manufacturing (people, environment, and technology-oriented)

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Preliminary Recommendations:

From the analysis of the World Manufacturing Forum Report Roadmap, recommendations include i) the extension of existing themes and/or ii) addition of new topics

I. Extension of existing major challenges:

Major Challenge 2: 'Implementing AI and machine learning to detect anomalies or similarities and to optimise parameters' and **Major challenge 3:** 'Generalising condition monitoring, to pre-damage warning on-line decision-making support and standardisation of communication scenarii to enable big data collection across huge (remote) sites'

Could be brought together as '**AI enabled/optimised manufacturing'** including / extended to:

- Data driven, cognitive manufacturing, hyper-connected intelligent machines, AI-driven cognitive operations and smart optimisation of resources
- Rapidly responsive manufacturing, global risks-resilient manufacturing
- Hyper-personalised manufacturing, mass customisation, human in the loop, exploiting social IoT Systems

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

Could be extended to:

- Integration of blockchain as a means of mitigating risk and increasing security
- Integration of IT, OT and ET

II. In case new themes would be added, these could relate to:

- **Topic 1:** Hyper-personalised manufacturing, human in the loop, inclusive manufacturing
- **Topic 2:** Cognitive manufacturing (AI enabled), rapidly responsive manufacturing (flexible production, agile, and responsive), global risks-resilient manufacturing
- **Topic 3:** Sustainable manufacturing and circular economy

Other new innovation related topics could include:

- Promote education and skills development for societal well-being
- Assist SMEs with digital transformation
- Encourage eco-systems for manufacturing innovation world-wide, involve all stakeholders
- Strengthen and expand infrastructures to enable future-oriented manufacturing

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3.4 CPS Roadmaps (Platforms4CPS, Road2CPS, Road4FAME, Scorpius):

Scope: Focus is on Cyber Physical Systems (CPS) including Cyber Physical Production Systems (CPPS). Domains include Manufacturing, Transport, Energy, Health, Smart Cities and Emergency & Crisis.

Emerging technological themes / future research priorities:

- (Real-time, big) **data analytics** and (collaborative) **decision support**
- **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
- **Modelling & Simulation**, visualisation, virtualisation, augmentation, **digital twin**
- **CPS (virtual) engineering** of large, more and more complex systems and **model-based systems engineering** including integrated, virtual, full-life-cycle engineering**,** high-confidence CPS, validation, verification, risk analysis and risk management
- **Agile, open plug and play CPS platforms**, vertical and horizontal digital technology platforms, federation of platforms, open interfaces
- **Safety, robustness, resilience, and dependability** including fault detection and mitigation for secure real-time and mixed-criticality systems, fail-safe operation of autonomous systems

Enablers:

- **Integration, interoperability, flexibility, reconfiguration** including semantic interoperability and models, openness and open standards, automatic (re-)configuration and plug-and-play
- **Standards** and CPS **reference architectures**
- **Cybersecurity, privacy** and **trust** including block-chain, distributed ledgers digital identities, trusted and adaptive security architecture, co-engineered safety and security
- Seamless **connectivity**, communication networks, NGI, 5G
- **Computing and storage** edge computing and edge cloud interactions, intelligent edge devices, HPC, quantum technologies, cognitive computing, neuromorphic computing, brain inspired computing, energy efficiency

Innovation accelerators:

- **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

Missions:

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- Digitization/CPS for a **Circular Economy** and reaching **Sustainability Goals**
- Track and trace, from cradle to cradle, resource efficiency, reduction of waste and pollution

Differences / Possible Gaps:

- **Trustable, AI-enabled (semi)autonomous Cyber Physical Production Systems (CPPS)**, for dependable, resilient factories, including cognitive systems, situation awareness, diagnostics, prognostics, large-scale data analytics, decision support based on 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

- **Missions: Digitization for a Circular Economy** and **reaching Sustainability Goals**

- **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, ethics

Preliminary Recommendations:

From the analysis of the CPS Roadmaps, recommendations include i) the extension of existing themes and/or ii) addition of new topics

<u>**I.** All major challenges are very relevant and should be kept but could be adapted/extended:</u>

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'

Could be extended to:

- Other means of modelling and simulation, visualisation, virtualisation, augmentation
- Co-engineering approaches, safety, security (and ethics) by design, DevOps
- Including the human as an integral part of the system
- Including the supply chain, value creation network
- Extend life-cycle to a circular economy approach

Major Challenge 2: 'Implementing AI and machine learning to detect anomalies or similarities and to optimise parameters' and **Major challenge 3:** 'Generalising condition monitoring, to pre-damage warning on-line decision-making support and standardisation of communication scenarii to enable big data collection across huge (remote) sites'

Could be brought together as '**AI enabled/optimised manufacturing'** including:

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- AI for adaptable/resilient factories; components and systems for condition monitoring, predictive maintenance, (predictive) process optimisation (predictive scheduling (?)), towards prognosis, self-x ... including the human as an integral part of the system
- AI for human machine/robot collaboration; sensors, components and systems for advanced automation, HMI (VR/AR/MR), human robot collaboration, (semi)autonomous robots, cobots, autonomous/shared/collaborative decision making, collaborative intelligence
- AI to support sustainable manufacturing in a circular economy (track-and-trace, cradle to grave, and energy efficiency

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

Could be extended to:

- Agile, open, composable plug and play platforms
- Orchestration / federation of (meta)platforms
- Decentralised, dynamic platforms
- Platforms that support AI at the edge
- Ledger-based platforms

<u>II. In case new themes would be added, these could relate to:</u>

- **Topic 1:** Trustable, AI enabled Cyber Physical Production Systems
- **Topic 2:** Human as part of the (Cyber-Physical)System
- **Topic 3:** Sustainable manufacturing in a Circular Economy

<u>Other new innovation related topics could include:</u>

- **Collaboration** across initiative sand domains, cross-fertilisation
- Access of **SMEs, start-ups and scale-ups** to the ecosystem
- **Openness**, open data, open innovation and open platforms
- T-shape, cross-disciplinary **education**, lifelong learning and (re/up)skilling
- CPS enabled **business models** and business services
- **Maintaining sovereignty** in key value chains
- CPS standardisation, **regulation**, liability, **privacy** and **ethics**
- Promote societal dialogue, enhance user acceptance and trust, create a **positive vision**

Advantages/added value ECSEL-JU Roadmap

Spanning various domains, cross-fertilisation possible

ECSEL Joint Undertaking

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3.5 European Roadmap for Industrial Process Automation (2018)

Scope: ProcessIT.EU is primarily focused on process automation and ICT for process industries (which includes Operational Technology (OT) in process networks) and was formed by various partners, including end users, technology suppliers, academia and public authorities. As a project incubator, ProcessIT.EU is innovation-driven and oriented towards identifying and implementing project activities that focus on new competitive automation technologies.

Emerging technological themes / future research priorities:

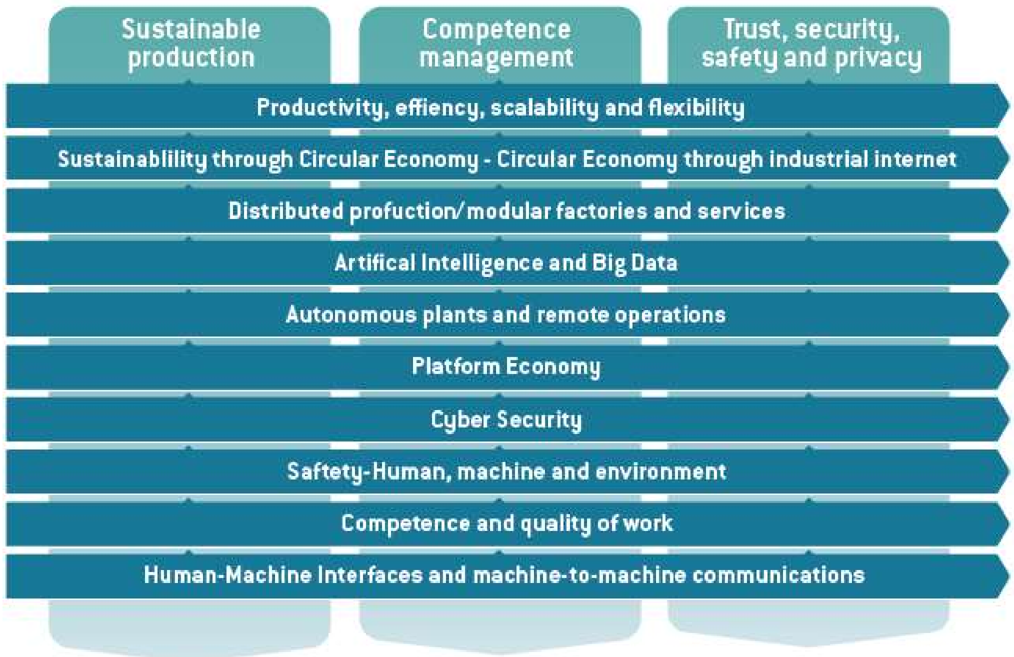

Figure 4: Top level needs and R&D areas (source: ProcessIT Roadmap)

Emerging Themes / Game Changers:

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

Enablers / Innovation accelerators:

- Sustainable production and related business models
- Digital services / technologies enabling new business models including product-oriented, user-oriented and result-oriented business models
- Competence management, including skills, management of critical knowledge

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- Trust, cybersecurity, safety and privacy, integrated operational cybersecurity management

Differences / Possible Gaps:

In general, ProcessIT.EU roadmap has a larger scope than ECSEL digital industry, focusing naturally on the process industry and its forthcoming research topics, so called game changers.

To summarise an overview of some of the findings on what is omitted/different in the ECS SRA major challenges from the ProcessIT.EU roadmap viewpoint:

- ProcessIT.EU game changers also aim for a broader scope such as artificial Intelligence/big data supported autonomous plants and remote operations
- Process industry as part of energy system
- Management of critical knowledge and data preservation/transparency 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
- Cyber-security management, ECSEL-JU however has its own section on cyber-security
- Digitalisation of value chains (utilising ecosystems)
- Personalised and targeted B2B marketing, smart contracts
- Service business around artificial intelligence
- New emerging business models for platform economy
- Novel HMIs and sensor systems

Preliminary Recommendations:

From the analysis of the ProcessIT Roadmap, recommendations include i) the extension of existing themes and/or ii) addition of new topics

I. Extension of existing 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 life-cycles'

Could be extended to:

- Live virtual twin including dynamic simulation of the processes based on models of the whole factory (artefact, equipment and process) to be created as automatically as possible

In addition, we could identify following topics as extensions:

- Complex system simulations and optimisation for 'Sustainability through Circular Economy'
- 'Sustainable virtual factory/twin - automatic and data-driven'
- Virtualisation and simulation of extended/distributed production processes
- Modelling and simulations use for training, risk evaluation and recovery action planning incl. cybersecurity
- Integration of safety aspects in simulation models
- AR/VR for HMI and M2M communication

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Major Challenge 2: 'Implementing AI and machine learning to detect anomalies or similarities and to optimise parameters' and **Major challenge 3:** 'Generalising condition monitoring, to pre-damage warning on-line decision-making support and standardisation of communication scenarios to enable big data collection across huge (remote) sites'

Could be brought together as '**AI enabled/optimised manufacturing'** including / extended to:

- Real-time data analytics including situational awareness for faster detection of problems and/or optimisation of production process when connected to predictive maintenance, process control and continuous monitoring
- Dynamic control and optimisation of output tolerances to allow adjustment of process parameters keeping production within acceptable tolerances; predictive maintenance enabling to compensate by adjusting process parameters.

In addition, we could identify the following topics as extensions:

- HMI and gamification; reinforcement learning
- M2M communication as enabler for machine learning
- Predictive- and condition-based maintenance optimisation

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

Could be extended to:

- Increased information transparency (between field and ERP) applying Industrial Internet paradigm (requiring data flow, interoperability, integration, standardisation)

In addition, we could identify the following topics as extensions:

- Platform Economy: B2B, IoT platforms, enhanced connectivity, platform interoperability (vendor neutral), data value sharing mechanisms and open specifications and interfaces
- Advanced lifecycle management/collaboration functionality for production process platforms
- Enabling new tool chains with integration of legacy systems

<u>II. In case new themes would be added, these could relate to:</u>

- **Topic 1:** Sustainability through Circular Economy – CE through Industrial Internet
- **Topic 2:** Safety – human machine environment; HMI and M2M communication
- **Topic 3:** Platform Economy incl. digitalisation of whole value chain
- **Topic 4:** Modular factories and autonomous production

<u>Other new innovation related topics could include:</u>

- Sustainable production, Circular Economy, incentives for responsible/sustainable production
- Business models, data ownership
- Competence management, trained and highly educated workforce, continuous training
- Safety, liability, cybersecurity, confidentiality, digital signatures/blockchains

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3.6 Eureka Smart Advanced manufacturing Technology Roadmap (2018)

Scope: The SMART Technology Roadmap focusses on high impact industrial manufacturing sectors including aeronautic, automotive, consumer goods, capital good and railway. Challenges derived from these sectors and taking specific enabling technologies and trends into account, derive the 6 SMART Research and Innovation priority fields:

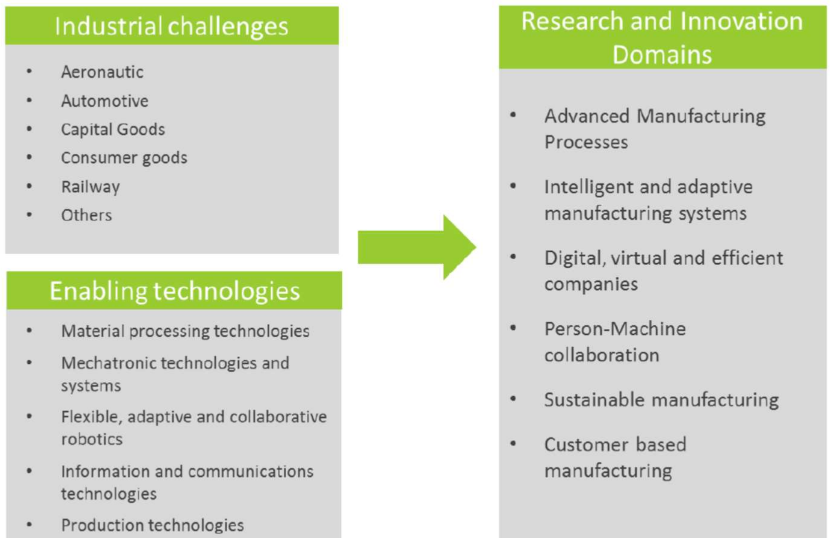

Figure 5: Industrial challenges, enabling technologies and research and innovation domains from EUREKA SMART roadmap

Emerging technological themes / future research priorities:

- **Advanced manufacturing processes**
- **Intelligent and adaptive manufacturing systems**, including innovative manufacturing equipment at components and system levels, mechatronics, control and monitoring systems
- **Digital, virtual and efficient companies**, including factory design, data collection and management, operation and planning, from real time to long term optimization approaches
- **Person-machine collaboration**, and enhancement of the role of people in manufacturing
- **Sustainable manufacturing**, including innovative processes and systems for sustainability in terms of energy and resource consumption and impact in the environment.
- **Customer-based manufacturing**, including involving customers in manufacturing value chain, from product process design to manufacturing associated innovative services

Enablers/Cross-cutting themes:

- Material processing technologies
- Mechatronic technologies and systems
- Flexible, adaptive and collaborative robotics
- ICT and production technologies
- 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

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Differences / Possible Gaps:

- Human-Machine interfaces (HMI), Virtual and Augmented
- Human-robot collaboration
- Person-machine collaboration: Enhanced role of people in manufacturing; inclusive, interactive and safe workplaces
- Customer-based manufacturing: Involving customers from product design to services, efficient adaptation to customer demands, customisation of products and processes
- Manufacturing as a service and additional services for manufacturing operation support
- Inspection, artificial vision, metrology
- Sustainable manufacturing: Innovative processes and systems for sustainability in terms of energy and resource consumption and impact in the environment

Preliminary Recommendations:

From the analysis of the SMART Roadmap, recommendations include i) the extension of existing themes and/or ii) addition of new topics

<u>**I.** Extension of existing major challenges:</u>

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’

Could be extended to:

- Advanced modelling and simulation tools for manufacturing process design and optimisation, including machine-process interaction
- Multi-disciplinary simulation tools for mechatronics engineering for ‘Intelligent and Adaptive Manufacturing Systems’
- Simulation techniques in manufacturing and assembly processes to increase ergonomics, first-time-right and production rates ‘Digital, Virtual and Efficient Companies’
- Simulation, concurrent engineering methods and rapid prototyping technologies for shortening development and certification cycles for ‘Customer-based Manufacturing’
- Cost models linked to design, productivity, end of life and recycling

Major Challenge 2: ‘Implementing AI and machine learning to detect anomalies or similarities and to optimise parameters’ and **Major challenge 3:** ‘Generalising condition monitoring, to pre-damage warning on-line decision-making support and standardisation of communication scenarii to enable big data collection across huge (remote) sites’

Could be brought together as ‘**AI enabled/optimised manufacturing’** including / extended to:

- ‘End to End’ data backbone for complete integration of production processes
- Use of **big data** and evolutionary algorithms for processes diagnosis, monitoring & control as well as **predictive maintenance**
- **Monitoring** and optimization of machines and equipment in real time
- **Predictive and proactive maintenance** based on advanced sensor information and processing

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- **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

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

Could be extended to:

- Data acquisition, storage and processing
- High performance and open communications and platforms
- Multi-platform solutions

II. In case new themes would be added, these could relate to:

- **Topic 1:** Human machine / human robot collaboration, HMI, enhanced role of workers and customers in manufacturing
- **Topic 2:** Sustainable manufacturing: Innovative processes and systems for sustainability in terms of energy and resource consumption and impact in the environment

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3.7 European Big Data Value Strategic R&I Agenda (2017)

Scope: 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.

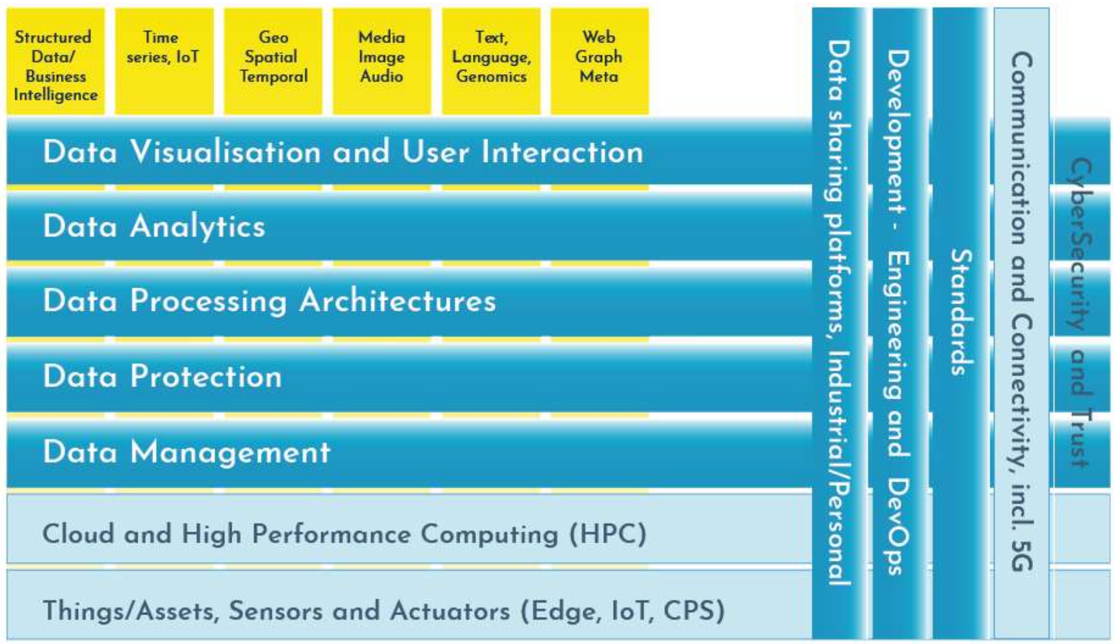

Figure 6: Big Data Value Reference Model (source: BVDA Roadmap)

Emerging technological themes / future research priorities:

- Visualisation and user interaction to support exploring/understanding effectively big data
- Data analytics to improve data understanding, deep learning, and meaningfulness of data
- Optimized and scalable data processing architectures delivering real-time analytics from vast amounts of sensor data streams
- Privacy and anonymization mechanisms to facilitate data protection (cybersecurity).
- Principles and techniques for data management for increasing amounts of data sources (e.g. sensors and social data) and their complexity

In BDVA/EFFRA roadmap alignment workshops, following challenges were identified with regards to the smart manufacturing industry:

- Smart factory scenario:
  - Factory modules semantic interoperability as producers, consumers and processors of data from heterogeneous sources.
  - Smart factory data annotation strategy, data quality and data availability
  - Data processing architecture (on premise or cloud), hybrid cloud and edge automation architecture and data in motion, data in rest integration.

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  - Prescriptive analytics in industrial plants, machine and data learning in QC, data analytics-human interaction improvements
  - Analytics based decision support for KPIs, embedded analytics in data at rest, simulation models and digital twins for analytics to perform optimisation
  - Sensitive data privacy in future workspaces, smart factory protection against cyberattacks, access control and data integrity for digital infra and selective anonymization
  - Context-aware visualisation, visual analytics and natural language interfaces
  - Cross-domain learning techniques and training environments
- Smart product lifecycle scenario
  - Pre-production data interoperability, post-production data cleaning and curation
  - Multi-company data merge and manufacturer/end-user data integration
  - Data at rest for pre-production and data in motion for post-production
  - Pre-processing product data and deep learning techniques
  - Real-time data analytics operations and digital twins alignment for complex products
  - Integration of physical systems modelling with complex software systems
  - Data confidentiality and IPR in pre-production and privacy preservation in post-production
  - 3D/AR/VR configurable visualisation in runtime
- Smart supply chain scenario:
  - Heterogeneous data in business ecosystems, data value chains and data traceability in value networks
  - Adaptive and flexible data management in supply chain and collaboration with data providers
  - Vertical data integration in supply chain and real-time data processing
  - Supply chain optimisation, risk analysis and decision support
  - Workforce management and prescriptive maintenance
  - Cybersecurity and trust in agile value networks
  - AR/VR technology integration to supply chain, customised user interfaces

Enablers:

- Big data standardisation, needs in both technology and data standardisation area
- Engineering and DevOps (big data value engineering, DevOps, QA and addressing multiple dimensions of big data value)
- Cybersecurity and Trust
- Data sharing platforms, both industrial and personal
- Cloud and HPC
- Connectivity and 5G

Innovation accelerators:

- Data science skills development
- Ecosystems and business models
- Policy and regulation (data-driven economy)
- Social perceptions and societal implications including trust and ethical issues

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- Digitisation of start-ups, industry and service sectors, specially focusing on ICT standards
- Digital innovation for modernising public services
- Stepping up investments in digital technologies and infrastructure

Differences / Possible Gaps:

In general, emphasis in BDVA roadmap vision are in data and its different layers, namely in data management, data protection, data processing architectures, data analytics and in data visualisation and user interfaces.

Currently, main focus in ECSEL could be seen in smart-factory related scenario whereas BDVA also addresses challenges in smart product scenario and in smart supply chain scenario as well.

Preliminary Recommendations:

From the analysis, recommendations include i) the extension of existing themes and/or ii) addition of new topics

I. Extension of existing 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 life-cycles'

Could be extended to:

- Simulations and digital twins for data analytics in HPDA (high performance data analytics) reference applications
- Simulations in novel data processing architectures for enabling new types of big data workloads (hybrid Big Data and HPC architecture)

Major Challenge 2: 'Implementing AI and machine learning to detect anomalies or similarities and to optimise parameters' and **Major challenge 3:** 'Generalising condition monitoring, to pre-damage warning on-line decision-making support and standardisation of communication scenarii to enable big data collection across huge (remote) sites'

Could be brought together as '**AI enabled/optimised manufacturing'** including / extended to:

- Visual data exploration, discovery and querying
- Artificial intelligence platforms
- AI and machine learning towards advanced business applications (distributed deep learning)
- Enhancing real-time capabilities of Big Data systems and platforms to handle high-intensity and highly distributed data and event streams.
- Predictive systems (such as recommendation engines) and prescriptive analyses
- Event and pattern discovery including discovery and prediction of rare real-time events

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

Could be extended to:

- Development of industrial data sharing platforms (IDPs) oriented towards proprietary (or closed) data, guaranteeing a trusted, secure environment within a clear legal framework, to monetise and exchange data assets
- Data lifecycle management and data governance
- Real-time architectures for data-in-motion
- Collaborative 3D and cross-platform data visualisation frameworks
- Artificial intelligence platforms

II. In case new themes would be added, these could relate to:

- **Topic 1:** Data integration/interoperability in different scenarios (smart factories, smart product lifecycle, smart supply chain)
- **Topic 2:** Data strategies (data in rest, data in motion, data value chains)

Other new innovation related topics could include:

- Skills development
- Ecosystems and business models
- Infrastructures
- Policy and regulation
- Social perceptions and societal implications including trust and ethical issues
- Trusted data-sharing environments, trust in data-driven decision-making and AI platforms
- Digitisation of start-ups and modernising public services

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3.8 HiPEAC Vision (2019)

Scope: The HiPEAC Vision 2019 (High Performance and Embedded Architecture and Compilation) analyses the current situation and new trends in advanced computing / ICT technologies. The document explores the situation from various perspectives including market, society and technological developments.

Emerging technological themes / future research priorities:

- Software used to write software
- Elements of Systems or SoS need to be able to dynamically adapt
- Development of 'intelligence at the edge' and cognitive CPS
- Architectural heterogeneity
- Accelerators and in-memory computing
- Networks on Chip (NoC)
- Inter-rack communication (e.g. Unshielded Twisted Pair (UTP))
- Storage in terms of volatile memories and non-volatile memories

Enablers:

- Emergence of 5G network
- Market availability and reduced cost of GPUs
- Security by design, blockchain
- HPC, cloud, fog and edge computing

Innovation accelerators:

- Digital skills are the fuel of innovation - ICT education, Learning platform trends like MOOCS
- Interoperability, standardization
- Societal vision, policy, legal

Differences / Possible Gaps:

- Themes related to advanced computing (not in Digital Industry Chapter) like neuromorphic computing, quantum computing, silicon-based CMOS technology limitations and alternatives
- Cognitive Cyber Physical Systems C^2PS
- Explainable, trustable AI
- Europe to aim at leadership in intelligence at the edge solutions
- HPC, edge computing, fog computing, cloud, edge ML and deep learning
- Emergent 5G network for mobile communication
- European Union (EU) should regain sovereignty and self-sufficiency in ICT
- Awareness of the societal and environmental impact of ICT
- Digital ethics

Preliminary Recommendations:

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From the analysis of the HiPEAC Vision, recommendations include i) the extension of existing themes and/or ii) addition of new topics

I. Extension of existing 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 life-cycles’

Could be extended to:

- HiPEAC points out that software plays an important role in making digital twin technology be usable in the manufacturing industry, and is a **compilation of simulation tools that include AR, VR, 3D modelling, and big data analysis**

Major Challenge 2: ‘Implementing AI and machine learning to detect anomalies or similarities and to optimise parameters’ and **Major challenge 3:** ‘Generalising condition monitoring, to pre-damage warning on-line decision-making support and standardisation of communication scenarii to enable big data collection across huge (remote) sites’

Could be brought together as ‘**AI enabled/optimised manufacturing’** including / extended to:

- Europe needs to ‘Accelerate, Specialize and Automate’ in order to embrace the future of AI
- Implementation of deep-learning algorithms
- Shift towards the edge, edge computing and high-performance data analytics
- Edge ML and Deep Learning to collaborate with ICT edge and cloud initiatives
- Ethical implications of AI
- ICT domains as a continuum, not as a silos

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

Could be extended to:

- Open source design for digital platforms
- Transparency, trust, and public understanding of technological tools

II. In case new themes would be added, these could relate to:

- **Topic 1:** Cognitive Cyber Physical Systems C^2PS and explainable, trustable AI
- **Topic 2:** HPC, 5G, HPDA, Edge ML

Other new innovation related topics could include:

- Ethics, social and environmental impacts (positive and negative)
- Digital skills

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3.9 Implementation Strategy Industrie 4.0- German Initiative (2016)

Scope: This roadmap 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. In particular, it serves to prepare Germany and its industry for the challenges of the future, and 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. The Industrie 4.0 implementation Strategy provides a very detailed guide about the use and implementation of different standards, reference architecture model, and overall the importance in structuring and working with a system of systems.

Emerging technological themes / future research priorities:

- Human-centred approach
- Systems engineering-reference architecture, standardisation, and semantics
- Security-by-design
- Sensor networks

Enablers:

- Cybersecurity
- Administrative shell
- Implementation of RAMI4.0
- Resource efficiency
- 5G Network infrastructure, new radio standards and near field technologies

Innovation accelerators:

- Employee re-training and upskilling
- Implementation of 'leanstruments' and 'communities of practice'
- Creation of new values networks
- Scalability and interoperability

Differences / Possible Gaps:

- Focus and emphasis on standardization
- Nestable, separable, and logical components and systems

Preliminary Recommendations:

From the analysis of the Implementation Strategy Industrie 4.0 Roadmap, recommendations include i) the extension of existing themes and/or ii) addition of new topics

<u>**I.** Extension of existing major challenges:</u>

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'

Could be extended to:

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- Modelling via the RAMI-architecture model
- Methods for modelling, calculation, simulation and optimisation
- Networking and individualisation of products and business processes leads to complexity, which is managed by means of modeling, simulation and self-organisation
- Virtual commissioning for factory and machine life cycles for pre-operating Industry 4.0 requirements
- 'Administrative shell', contains all data of the real component like a digital twin

Major Challenge 2: 'Implementing AI and machine learning to detect anomalies or similarities and to optimise parameters' and **Major challenge 3:** 'Generalising condition monitoring, to pre-damage warning on-line decision-making support and standardisation of communication scenarii to enable big data collection across huge (remote) sites'

Could be brought together as '**AI enabled/optimised manufacturing'** including / extended to:

- Sensor networks
- Data analysis
- (Autonomous) decision-making

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

Could be extended to:

- RAMI 4.0 as a universal standards framework

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.

<u>II. In case new themes would be added, these could relate to:</u>

- **Topic 1:** Reference Architectures and Models, Implementation of RAMI, Standardisation

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<u>Other new innovation related topics could include:</u>

- Standardisation
- Area-wide broadband infrastructure for industry
- Work organisation and workplace design
- Training and re/up-skilling
- Legal framework conditions
- Business models, data ownership

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4 Comparing Roadmap Scopes

Whereas most roadmaps funded by the European Commission H2020 Programme, have a focus either on a specific technology (e.g. CPS, computing, big data analytics) or domain (e.g. manufacturing), the ECSEL SRA spans from electronic components to systems and across many application domains.

The darker the colour, the more in-depth the theme is handled:

- dark blue: focus,
- middle blue: addressed,
- light blue: only mentioned
- no colour: not mentioned

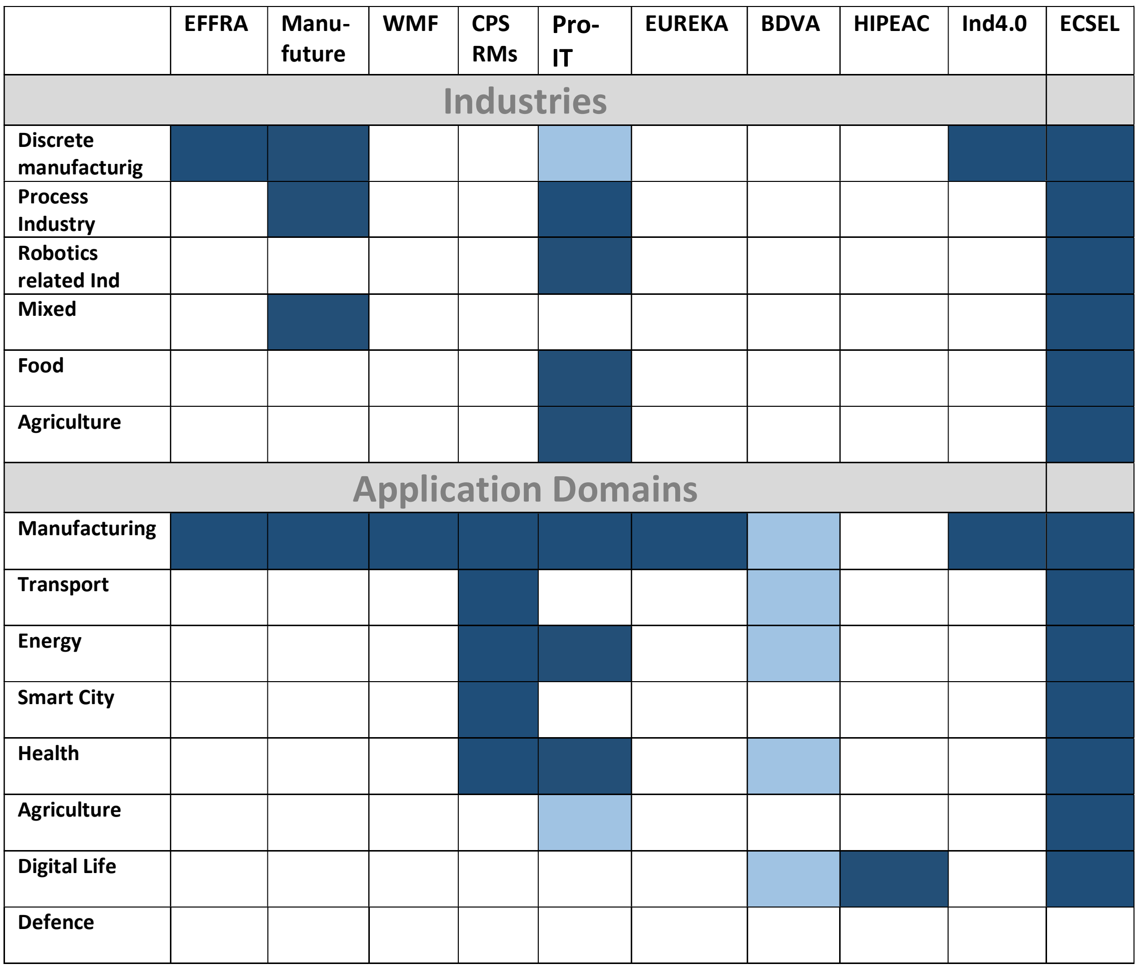

Figure 7: Matrix of CSA-Industry4.E selected roadmaps and their industry and application domains in comparison with ECS SRA and the ECSEL-JU MASP
(The darker the colour the more in depth the theme is handled - focus, addressed, only mentioned)

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5 Comparing Roadmap Priority Themes

To visualise the different priority themes of various related roadmaps, a **Priority Matrix** has been built.

	EFFRA	Manu-future	WMF	CPS RMs	Pro-IT	EUREKA	BDVA	HIPEAC	Ind4.0	ECSEL
COMPONENTS (for Digital Industries)										
Sensors / Actuators										
SYSTEMS (for Digital Industries)										
Systems Engineering										
TOPICS (for Digital Industries)										
Robotics / Automation										
Platforms										
Model & Simulation										
Digital Twin										
CPS/CPPS/ IoT										
Data Analytics										
Decision support										
Autonomy										
AI machine learning										
Embedded AI										
AI enabled manufact.										
Predictive Maintan.										
Zero defect manuf.										
Life cycle MGT										
Humans in the loop										
Circular Economy										
ENABLERS – other chapters in ECS SRA – cross-cutting										
Communi-cation, 5G										
Computing Cloud, Fog, Edge, HPC										
Safety, Reliability										
Privacy & Trust										
Standard-isation										

ECSEL Joint Undertaking

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Figure 8: Matrix of selected roadmaps and their relation to digital industry topics (The darker the colour the more in depth the theme is handled - focus, addressed, only mentioned)

Matrix Non-Tech / Innovation Accelerators

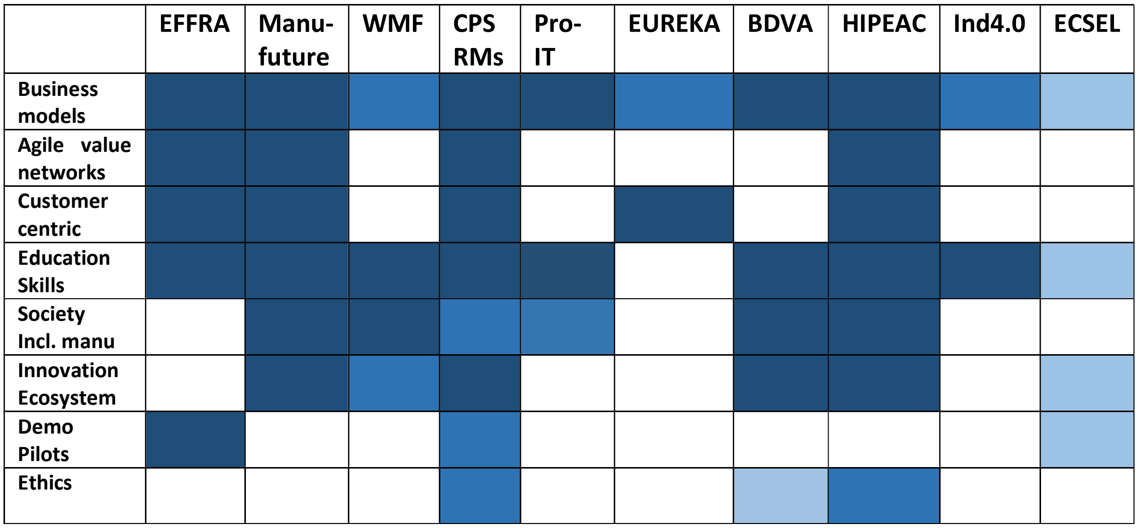

Figure 9: Matrix of selected roadmaps and their relation to non-tech topics/innovation accelerators (The darker the colour the more in depth the theme is handled - focus, addressed, only mentioned)

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6 Identified Emerging Topics and Possible Gaps

The analysis of the roadmaps of the previous section, revealed two quite prominent gaps (described in most of the other roadmaps but barely elaborated or not mentioned in the ECS SRA Digital Industry Chapter), namely 'Sustainable manufacturing in a Circular Economy' and 'Human centred manufacturing'. Next to this, the trend of 'AI enabled cognitive, resilient factories' was focused more strongly in the other roadmaps. Another new theme (not yet mentioned in other roadmaps but within expert discussions) is the 'Other twin'/Systems Engineering/Factory Design'. In addition, some of the emerging innovation accelerators are underrepresented within the ECS SRA and could be enhanced in upcoming versions.

- **Topic 1:** Human centred manufacturing
- **Topic 2:** Sustainable manufacturing in a Circular Economy
- **Topic 3:** AI enabled cognitive, resilient, adaptable factories
- **Topic 4:** Multi-technology co-engineering enabled by digitalization
- **Topic 5:** Innovation Accelerators / Business models / Skills

In more detail, the topics to fill the current gaps comprise of:

Topic 1: 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

Topic 2: Sustainable manufacturing in a Circular Economy

- 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

Topic 3: AI enabled resilient, adaptable factories

- Artificial Intelligence supported flexible, resilient, adaptive manufacturing ecosystem, 'Dynamic Virtual Value Networks'
- Cognitive manufacturing (AI enabled), rapidly responsive manufacturing (flexible production, agile, and responsive), global risks-resilient manufacturing

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- Trustable, AI enabled Cyber Physical Production Systems
- Cognitive Cyber Physical Systems C^2PS and explainable, trustable AI
- Supported by HPC, 5G, HPDA, Edge ML

Topic 4: 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.

Topic 5: Innovation Accelerators / Business models / Skills

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

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7 Preliminary GAPs and Recommendations for Possible Updates in the Digital Industry Chapter of the ECSEL SRA

In contrast to the roadmaps analysed, the ECS SRA chapter on 'digital industry' focusses on discrete manufacturing and process industries including all sectors (e.g. food and agriculture) as well as on factories and farms. This wider scope including these very related fields lends to good possibilities of cross fertilisation of otherwise separated fields and to exploit these synergies in an optimal way. Moreover, the 'domain chapters' are all cross-linked to the 'technology chapters', enabling the identification of cross-cutting themes and cross-fertilisation. Nevertheless, when analysing the gaps it becomes clear, that in other roadmaps having a more narrow focus allows scope to go into more depth in specific areas (e.g. standards in manufacturing). The authors of this document are aware that specific advantages come along with some trade-offs, but tried to propose implementable recommendations for themes that could be refined, deepened/extended within the ECS SRA digital industry chapter. Next to this, new trends and themes have emerged, which might not yet be that prominent or even missing in the ECS SRA / digital industry chapter. These new trends, like 'human in the loop' or 'circular economy' could be included under the major challenges, or be specified as a new 'stand-alone' major challenge. Moreover, a number of non-technical, innovation related challenges like new 'business models' or 'skills development' could be enhanced in the ECS SRA (digital industry or cross-cutting chapters).

The preliminary recommendations at hand, are subdivided into proposals for

- refinements/extensions of the current 4 major challenges,
- additions in terms of new technological topics,
- additions in terms of new non-tech / innovation related topics.

I Refinements/adaptions/extensions to the current major challenges:

The current 'major challenges' of the 'Digital Industry' Chapter are:

- **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 optimise parameters'
- **Major challenge 3:** 'Generalising condition monitoring, to pre-damage warning on-line decision-making support and standardisation of communication scenarii to enable big data collection across huge (remote) sites'
- **Major challenge 4:** 'Developing digital platforms, application development frameworks that integrate sensors/actuators and systems'

Through our analysis, all 'major challenges' have been assessed to be still very relevant and should indeed be kept in the next iteration of the ECS SRA, but can partly be extended with the evolving trends identified. Major challenge 2 and 3 were found to be very related (even overlapping) and are proposed to be fused to one new major challenge for 'AI enabled/optimised manufacturing'. New trends, especially 'Circular Economy' have become very prominent and are proposed to be added as a fourth major challenge.

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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'

In major challenge 1, the digital twin is comprehensively described and specifically elaborated for 'virtual commissioning'. Moreover 'machining process simulation' and is described and the wider context for modelling and simulation, digital design and documentation mentioned. (Other) priority areas include multi-simulation, tracking mode simulation, model adaption, simulator-based design. There is a link to major challenge 4, as digital platforms can provide the infrastructure to automate background processes. Interoperability is a barrier to be overcome, possibly by a standard to make digital twins 'communicate'. As indicated in the headline, digital twins are to be developed for the evaluation of industrial assets at all factory levels and over the system or product life-cycle.

The analysis of different roadmaps (and discussions with experts) revealed, that 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. Moreover, the product life-cycle could be extended 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 (to formulate D1.3 recommendations):

- Further methods for modelling and simulation
- Human in the loop
- Circular Economy
- Standardisation
- Business models
- Skills

Major Challenge 2: 'Implementing AI and machine learning to detect anomalies or similarities and to optimise parameters' and **Major challenge 3:** 'Generalising condition monitoring, to pre-damage warning on-line decision-making support and standardisation of communication scenarii to enable big data collection across huge (remote) sites'

Major challenge 2 focuses on deep learning and mentions CPS/ Industrial Internet, big data, machine learning, AI, which today are not yet transparent nor practical to use. Local edge-based intelligence is seen as an opportunity for Europe. Major challenges 3 refers to advanced condition monitoring (towards 5G condition monitoring), which can be supported by AI and is also very linked to MC1, modelling and simulation/digital twin, as key priority areas include (automated) modelling and analytics tools and multi-variant and multi objective-simulation and optimisation. Increased efficiency, flexibility and robustness of the production process is expected.

As major challenge 2 and 3 were found to be very related they are proposed to be fused to one new major challenge for 'AI enabled/optimised/cognitive manufacturing'. This 'new major challenge would then build on the former two, and would be 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 to not only support reconfigurable

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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 (to formulate D1.3 recommendations):

- (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

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

Major challenge 4 focuses on digital platforms providing computing, storage and networking services between (edge) devices and data centres with AI capabilities. The platform landscape is still very heterogeneous on the supply and demand side. To support interoperability, the IICF and RAMI is mentioned, as standardisation will be key. Questions about meta-platforms, integrating AI, performance, security and impact on the environment are raised. Priorities are on future industrial and engineering applications, prepare for 5G, low power consumption, (semi)autonomy, and trusted (safe and secure by design) platforms.

The analysis of different roadmaps confirms, that the platform landscape is still very fragmented, with open and closed, vertical and horizontal platforms in different development stages and for various applications. There is a strong need for interoperability / standardisation and orchestration / federation of platforms. The trend heads towards agile, composable, plug and play platforms (also usable for SMEs) and more decentralised, dynamic platforms supporting AI at the edge. Future (ledger based) could provide common services on trusted multisided markets / ecosystems.

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 (to formulate D1.3 recommendations):

- Digital Platforms Technology
- Digital Platforms Standardisation
- Digital Platforms Economy / Business / Society

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8 Preliminary Recommendations for 'Special Topics'

Next to the process of updating the ECS SRA (and ECSEL-JU MASP), a set of 'special topics' has been requested to be proposed for the Digital Industry area as a proposal of the upcoming ECSEL-JU calls. Derived from the gap analysis performed, a choice of 'special topics' was made by the consortium together with the LIASE, to feed into discussions of the upcoming Governing Board Meeting.

The following 'special topics' call texts were proposed:

Special Topic 1:
Artificial intelligence (AI) enabled inclusive and resilient manufacturing – The Human in the Loop

Special Topic 2:
ECS for Sustainable manufacturing and Circular Economy

Special Topic 3:
Component, and systems for modelling and simulation of cognitive, adaptive, resilient factories at all factories levels and covering the full life cycle

Below the 3 'special topics' are shown in more detail.

Special Topic 1:

Artificial intelligence (AI) enabled inclusive and resilient manufacturing – The Human in the Loop

Specific scope and objectives

AI methods are revolutionary in many industrial areas, but in most cases, their autonomy is limited specifically where robustness and resilience are required in complex manufacturing environments. **Participation of humans in the control loops** remains necessary to ensure maximum performance and adaptability to change. A central issue of these systems is how humans and AI agents collaborate at the human-machine interface will need to adapt during changing and critical situations.

Another issue for the common use of AI in manufacturing is the difficulty that intelligent algorithms must communicate appropriately the reasons of their decisions, and how they will help achieving the mission objectives. A lack of communication will create trust issues and misunderstandings, degrading the performance of the joint cognitive systems composed of humans and AI, and there is a need for '**explainable AI'** that humans build trust.

AI for adaptable/resilient factories: AI enables the creation of (semi-)autonomous but still dependable factories/CPPS (Cyber Physical Production Systems) that can react to unforeseen, unpredictable, evolving behaviours. This also includes humans (e.g. the work force).

AI for human machine/robot collaboration: AI, supported by the relevant sensors/actuators (components) and data analytics tools, can enable and optimize efficient, adaptive and inclusive human machine collaboration. Going a step further, increasing levels of autonomy, shared decision

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making and collaborative intelligence (natural and artificial), can bring systems to higher levels of resilience.

Proposal should cover some of the listed aspects but are not limited to:

- Demonstrate a clear added value: higher process quality and robustness, reduced maintenance and down-time, higher flexibility, reduced consumption of process resources….
- Integration of AI in optimization processes such as Condition monitoring, predictive maintenance, (predictive) process optimisation (including humans in the system), predictive scheduling, towards prognosis, self-x ...
- Combination of data and model-driven AI:
    - Use of explicit functional models as knowledge in cognitive control loops. Explore model-based and model-driven systems to ease the issues of trust in joint cognitive systems.
- AI-based interactive learning and training systems Autonomous/shared/collaborative decision making
- Socio-Cyber-Physical Systems (where humans play a role either as part of the plant, as part of the controller and/or as part of the environment) in manufacturing.
- Developing and demonstrating how AI-related computations are implemented in distributed architectures, modern embedded-edge/fog-cloud architectures, etc. Modular, reusable user interface assets for monitoring and visualisation. These assets need to improve the comprehension and reasoning by human users of the behaviour of AI agents during its pursuit of high-level mission objectives.
- Investigate how to improve the representation of system behaviour and operative limits in order to ensure a smart integration of humans and AI agents.
- Joint cognitive systems for real-time production scheduling, where the responsibility of taking decisions to optimize production, including times when a disruption event happens, is shared between human and AI.
- Investigate systems that learn from user input at runtime, and not design time.
- AI for Machine learning made easy to overcome the lag time required for programming and predictive modelling.
- AI for scheduling, based on Data and manufacturing requirements (i.e. allow for human interaction in the scheduling process to avoid AI to dictate the process can lead to data driven errors).
- Data enabled decision making where AI can facilitate efficiency work and lessen the chances of errors while holding highest quality standards minimise an employee’s dependency on others to take a decision

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Special Topic 2:

ECS for Sustainable manufacturing and Circular Economy

Specific scope and objectives

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.

Proposal should cover some of the listed aspects but are not limited to:

- Techniques, methods and tools for adoption of circular economy with ECS products
- Methods, tools, components and Cyber physical systems to improve reuse, refurbishment and recycling of ECS products giving support to traceability management and Support decision through the use of Cyber Physical systems, simulation, data analysis and AI techniques.
- Techniques, methods, tools and systems to improve energy and resource efficiency in manufacturing by sensors, components and systems. The challenge is the reduction of energy consumption in the manufacturing process, either by the reuse of wasted energy or by optimizing the processes and agents involved.

Special Topic 3:

Component, and Systems for Modelling and Simulation of Cognitive, Adaptive, Resilient Factories at All Factories Levels and Covering the Full Life Cycle

Specific scope and objectives

Including topics, we currently have under Digital Twin – towards visualisation/ virtualisation/ augmentation (human can be part of it with wearables/glasses, or being modelled etc) Developing digital twins, simulation models for the evaluation of industrial assets at all factory levels and over system or product life-cycles.

Modelling and simulation play a key role in managing the increasing complexity of (socio-)technical systems, e.g. as digital twins being dynamic digital representations of industrial assets, whole factories (including the human workers) or even inter-connected factories / supply chains (ECS value chain). A holistic engineering approach is required to span the different technical disciplines and prove end-to-end engineering across the entire value chain.

Proposal should cover some of the listed aspects but are not limited to:

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  - Components, architectures, (sub-)systems for modelling and simulation enabling virtual design/development/engineering commissioning and operation of dynamically evolving factory-floor assets and human-machine-interaction.
- Integration, testing and experimentation of innovative technologies that will improve modelling and simulation including but not limited to:
  - (dynamic) digital twin, visualisation, virtualisation, augmentation
  - HMI, dashboards, wearables
  - Simulation based learning and training of operators, human in the loop simulations

9 Assessment of Focus Themes of Lighthouse Industry 4.E Projects

The Industry4.E Lighthouse Projects mapped in D1.1, specifically for synergies and complementarities were further analysed. A further step in the data collecting process involved meeting with key stakeholders of the Industry4.E Lighthouse at an event in Bucharest, Romania on June 19th, 2019 as part of the annual ECSEL-JU Symposium 2019. The workshop, entitled "Shaping the Future Lighthouse Industry 4.E" featured a session where the coordinators presented project results and future projections of research areas needed in their sector to propel their project forward, as well as the gaps, obstacles, and urgent challenges that they feel would be necessary to be included in future funding calls.

Following this face-to-face meeting, consortium members of the CSA compiled notes and segregated the slides dealing with 'urgent challenges' and 'future projections' and proceeded to build a matrix based on this feedback for each Lighthouse project. The matrix features color-coding based on the project's perceived domain focus area, major challenges addressed from the ECS Strategic Research Agenda (SRA), and technical & non-technical emerging themes that are not yet included in the ECS SRA. Since this matrix was built with several information points, the research team of the consortium sought to verify them with the same stakeholders of the Industry4.E. community.

To do this, over the course of several weeks, the researchers held individual interviews with each stakeholder (via teleconference calls). These stakeholders included coordinators of Industry4.E Lighthouse projects, reviewers of digital industry-focused European projects, and authors of the ECS SRA digital industry chapter. Based on the information given in each interview, the matrix was altered accordingly, and qualifying statements were added if a particular project only partially fulfilled the domain focus area, challenge, or emerging themes. Non-Industry4.E Lighthouse Project coordinators were asked in particular about whether the recommendations put forth by the consortium were indeed 'on track' with real-life trends.

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		SWARMs))) swarms.eu	MANTIS mantis-project.eu	semi40.eu	Delphi4LED delphi4led.org	SCOTT scottproject.eu	I-MECH i-mech.eu	Productive 4.0 productive40.eu	iDev40 idev40.eu	afarcloud afarcloud.eu	MADEin4	ARROWHEAD TOOLS https://www.arrowhead.eu/arrowheadtools
Domains	***Systems and Components Architecture, Design, and Integration***											
	Connectivity and Interoperability											
	Safety, Security, and Reliability											
	Computing and Storage											
	Process Technology, Equipment, Materials, and Manufacturing for ECS											
Major Challenges	***MC1: Developing digital twins, simulation models for the evaluation of industrial assets at all factory levels and over system or product life-cycles***											
	MC2: Implementing AI and machine learning to detect anomalies or similarities and to optimise parameters											
	MC3: Generalizing condition monitoring, to pre-damage warning online decision-making support											
	MC4: Developing digital platforms, application development frameworks that integrate sensors and systems											
Emergin	***Human centred manufacturing***											

ECSEL Joint Undertaking

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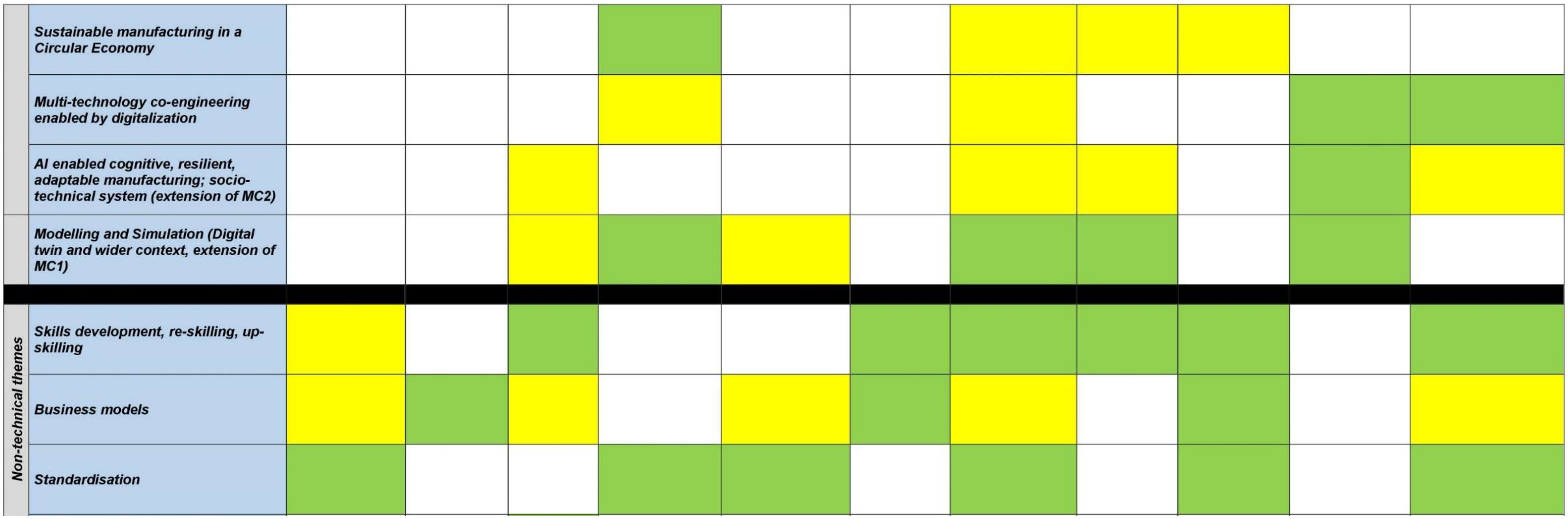

Figure 10: Matrix of Industry 4.E Lighthouse Projects and their relation to major challenges as well as emerging themes and innovation accelerators (green – main focus; yellow - tackled but no main focus of the project; white – not tackled)

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The contributions to domains and major challenges have already been analysed in detail in D1.1.:

- 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 the main capability. This is followed by 'safety, security and reliability' which is only addressed by 1 project as the main capability.
- Regarding the main challenges of the Digital Industry chapter addressed in the Industry4.E projects, the MC 4 is the most addressed one of the four challenges, followed by MC 1 and MC 2. MC 3 is the challenge covered by least projects.

Regarding the emerging themes as identified during the gap analysis, the projects already partly contribute to them, although often not yet a major focus:

MANTIS addresses **Human Centred Manufacturing** partially as during the design of HMI components, human aspects were considered

SemI40 addresses **AI enabled cognitive, resilient, adaptable manufacturing; socio-technical system (extension of MC2)** as project results indicate that development of algorithms for cycle-time prediction development of new deep-learning algorithms were key results in the project research work. Regarding **Modelling and Simulation (Digital twin and wider context, extension of MC1)** the project achieved the development of digital twin models for product processing & sensor integration.

Delphi4LED addresses **Sustainable manufacturing in a Circular Economy** as Increased reliability of LED components through thermal simulations and modelling tools. In addition, improved reliability of modules, devices and systems including LED components through thermal simulations combining environmental sensor information of ambient temperature. Also, **Multi-technology co-engineering enabled by digitalization** with utilization of electrical-optical-thermal digital LED model in simulations and modelling. And **Modelling and Simulation (Digital twin and wider context, extension of MC1)** with LED component digital twins implemented and utilized with project demonstrators.

SCOTT partially addresses the theme **Modelling and Simulation (Digital twin and wider context, extension of MC1)** with channel models, link layer simulators.

Productive4.0 addresses **Human Centred Manufacturing,** as Human interaction is considered in the Productive4.0 platform framework. Enhanced collaboration between Human and Machines is one of the expected impacts in WP3 (obj 3: Providing the Industry with IoT enabling components). And Human centred I4.0 methods are considered in some use cases. There are also use cases using AR and VR for simulation and logistics. And standards such as IEC SC65A WG 17 – Human factors – functional safety (includes influence of human factors in all life cycle phases on functional safety of automation systems and devices, including development and operations resp. maintenance) are considered. It also addresses **Sustainable manufacturing in a Circular Economy** with goals such as improving sustainability in production: Improved energy/utilisation efficiency of the manufacturing processes (cheaper and more sustainable products), lifecycle management for improving sustainability. Sustainability by using second life batteries. **AI enabled cognitive, resilient, adaptable manufacturing; socio-technical system (extension of MC2)** is also addresses with the Productive4.0 collaborative

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system that will include both autonomous units / subsystems and an efficient high-level management support system. Moreover, **Modelling and Simulation (Digital twin and wider context, extension of MC1)** with Digital twins of processes, components of a production plan, devices, commissions, to create products, supply chains, production system, manufacturing system are considered.

iDev40 addresses **Human Centred Manufacturing** as one of main project objectives states that the project is focused on 'enhancing innovation capability by a human-centred design of ECS development processes, production systems and value chains'. And **Modelling and Simulation (Digital twin and wider context, extension of MC1)**: Project is using demonstrators to implement digital twin concepts along the value chains.

AFarCloud addresses **Sustainable manufacturing in a Circular Economy** as monitoring sensors improve production efficiency and yield. For example, water usage optimization on organic vineyards http://www.afarcloud.eu/spain-local/.

MADEIn4 will work in **AI enabled cognitive, resilient, adaptable manufacturing; socio-technical system (extension of MC2)** developing predictive yield system in the manufacturing lines, using machine learning techniques and **Modelling and Simulation (Digital twin and wider context, extension of MC1)** with topics such as Virtual commissions and Digital twinning.

In Arrowhead Tools, **Multi-technology co-engineering enabled by digitalization** is tackled, the solution of the project can help with this emerging theme and it is addressed in use cases: Use case - Integration of electronic design automation tools with product lifecycle tools. **AI enabled cognitive, resilient, adaptable manufacturing; socio-technical system (extension of MC2)** is also tackled allowing evolving systems.

In general, the projects are partially addressing the emerging themes and in few cases are tacked as main objective of the project and with the required extension.

Regarding the **non-technical themes** or 'innovation accelerators', these are partly addressed by the projects.

SWARMS addresses **Skills development, re-skilling, up-skilling** with training sessions in conferences, **Business Models** and **Standardization** activities in WP9.

In MANTIS, they have worked in **Business models**: They have matured a number of new, Industrial Business Models, and will show the Industry how can a Maintenance Business Model be transformed into an Innovative product and service based Business Model, and what is even better, have been able to generate a model for economic evaluation and quantification of the process of transforming current models into the innovative ones.

In SemI40, they have worked in **Business model** aspect of digital platform deployment. Regarding, **Skills development, re-skilling, up-skilling**, project included research in job development in the I4.0 sector, including job requirements and necessary training in production and processes. **Others**: Research within the project has also focused on the social impact of jobs in the I4.0 sector.

Delphi4LED addresses **Skills development, re-skilling, up-skilling; Business models** (New simulation and modelling capabilities created to software) and **Standardization** activities are on-going.

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SCOTT addresses **Business models** partially in the exploitation task and **Standardization** in the Standardisation task with involvement in standardization bodies such as ETSI, ISO JTC1 WG5… Moreover, a liaison has been defined between SCOTT and the ISO JTC1 WG5, where they target to align and contribute with the SCOTT reference architecture and ongoing standardization activities. Another successful standardization output of the 1st year is that the SCOTT security development is already reflected in regulator guideline.

I-MECH addresses **Skills development, re-skilling, up-skilling** in a Training task and **Business models**, final exploitation and sustainability plan as part of Exploitation activities.

In Productive4.0 regarding **Skills development, re-skilling, up-skilling**: training workshops and training tasks on specific plant architecture implementation and automation components integration using the platform framework in WP1. A gap is seen in the societal impacts. Coordination with Arrowhead tool for joint training tasks. Regarding **Business models**: New service and business models based on mainly open source software and accelerated by the implementation of digital platforms (in WP7: The Productive4.0 exploitation framework). And **Standardization**: WP6 Standardisation, Objective 6: Influence relevant standards in the Industry.

iDev40 is working on defining skills profiles of factory employees, and addressing digitalisation challenges at industrialisation facilities (**Skills development, re-skilling, up-skilling**).

AFarCloud addresses **Skills development, re-skilling, up-skilling:** Agriculture domain knowledge for companies and research institutes. Cloud based services and architecture design. **Business models:** Manufacturer-independent platform with interfaces for sensors and services. And **Standardization*:*** Manufacturer-independence, defined interfaces, defined data formats.

In Arrowhead Tools, **Skills development, re-skilling, up-skilling**: Training and education are addressed in the project. A special use case is devoted to training: use case ARROWHEAD framework training tool. **Standardisation** activities are foreseen in WP10- Standardisation. **Business models** *are tackled* but not a priority: New business models will be developed by partners of the project. For the exploitation: Extension of companies' portfolios of services, including the creation of new business models e.g. servitisation of products.

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10 Conclusions

This deliverable presents the results of the gap analysis performed in CSA-Industry4.E task 1.2. It presents an analysis of relevant roadmaps and Industry4.E Lighthouse Projects in order to identify emerging topics and possible gaps as well as recommendations for updates within the ECS SRA and related special topics for digital industry.

The **gaps and emerging themes** identified through the roadmap analysis by the CSA include:

- Human centred manufacturing
- AI enabled cognitive, resilient, adaptable factories
- Sustainable manufacturing in a Circular Economy
- Multi-technology co-engineering enabled by digitalization
- Innovation Accelerators including new business models, skills and standardisation

These themes were discussed with the Industry4.E LIASE and ECS SRA 'Digital Industry Chapter' writing team and revealed broad confirmation. Upon request of the ECSEL-JU and in close collaboration with the Industry4.E LIASE, these themes were formulated into 'special topics' to be used to update the upcoming ECS SRA and ECSEL-JU MASP. The first two topics were combined into '**Artificial intelligence (AI) enabled inclusive and resilient manufacturing – The Human in the Loop**' to be proposed as a special topic to the ECSEL-JU Governing Board. The other topics were discussed in more depth within the ECS SRA – Digital Industry Chapter writing team and formulated into the 2020 update.

In parallel, the Industry4.E Lighthouse Projects were assessed against the emerging themes, and as these were not in the ECS SRA before, the gaps could also be confirmed here, even though some projects already aimed towards some of the emerging topics. In addition, the Industry4.E Lighthouse Project representatives were asked about gaps and emerging themes within a collaboration meeting as well as individual interviews, and broad consensus could also be found here. What is more, results from this data collection can be used into further updates of the SRA. The contribution of such industry leader input via the Lighthouse Projects is vital, as it amplifies the true needs of digital industry at the ground-level in the European market.

Overall, topics of high priority were seen to be the **human centred and AI enabled manufacturing** as well as **sustainable manufacturing in a circular economy**. Regarding the non-technical themes, **skills** and **standardisation** ranked highest, and were recommended for further uptake in ECS SRA updates.

The results will now feed into CSA-Industry4.E task 1.3 in support of the Industry4.E Lighthouse, to formulate more detailed recommendations for further ECS SRA updates.

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11 References

2018 World Manufacturing Forum Report: Recommendations for the Future of Manufacturing. World Manufacturing Forum, 2018, *2018 World Manufacturing Forum Report: Recommendations for the Future of Manufacturing*, www.worldmanufacturingforum.org/report.

Athanassopoulou, Nicky, and Haydn Thompson. *Road2FAME: Strategic Research & Innovation Roadmap and Business Opportunities for ICT in Manufacturing*. Steinbeis Edition, 2015, *Road2FAME: Strategic Research & Innovation Roadmap and Business Opportunities for ICT in Manufacturing*, download.steinbeis-europa.de/publikationen/Road4FAME_2015_Booklet_Strategic-Research-and-Innovation-Roadmap-and-Business-Opportunities-for-ICT-in-Manufacturing.pdf.

"EFFRA Vision for a Manufacturing Partnership in Horizon Europe: 2021-2027." *Https://Www.effra.eu/Sites/Default/Files/190312_effra_roadmapmanufacturingppp_eversion.Pdf*, EFFRA, 2019, www.effra.eu/sites/default/files/190312_effra_roadmapmanufacturingppp_eversion.pdf

Eureka Smart Advanced Manufacturing Technology Roadmap. SMART, 2018, *Eureka Smart Advanced Manufacturing Technology Roadmap* , www.smarteureka.com/mediafiles/2/1517507429-20180201-smart-cluster-technology-roadmap-en.pdf.

European Big Data Value: Strategic Research and Innovation Agenda. BDVA: Big Data Value Association, 2017, *European Big Data Value: Strategic Research and Innovation Agenda*, www.kowi.de/Portaldata/2/Resources/horizon2020/coop/BDVA-SRIA-4.pdf.

HiPEAC Vision 2019: HIGH PERFORMANCE AND EMBEDDED ARCHITECTURE AND COMPILATION. HiPEAC CSA, 2019, *HiPEAC Vision 2019: HIGH PERFORMANCE AND EMBEDDED ARCHITECTURE AND COMPILATION*, www.hipeac.net/vision/2019/.

Implementation Strategy Industrie 4.0: Report on the Results of the Industrie 4.0 Platform. Bitkom E.V., VDMA E.V. and ZVEI E.V, 2016, *Implementation Strategy Industrie 4.0: Report on the Results of the Industrie 4.0 Platform*, www.zvei.org/fileadmin/user_upload/Presse_und_Medien/Publikationen/2016/januar/Implementation_Strategy_Industrie_4.0_-_Report_on_the_results_of_Industrie_4.0_Platform/Implementation-Strategy-Industrie-40-ENG.pdf.

Lindström, John, et al. *EuropeanRoadmapfor Industrial Process Automation*. ProcessIT.eu, 2018, *EuropeanRoadmapfor Industrial Process Automation*, www.processit.eu/Content/Files/ProcessIT.EU-roadmap_ver2_final_4-Sep-2018.pdf.

MANUFUTURE Vision 2030. 2018, *MANUFUTURE Vision 2030*, www.manufuture.org/wp-content/uploads/Manufuture-Vision-2030_DIGITAL.pdf.

Reimann, Meike, and Carsten Rückriege. *Road2CPS: Priorities and Recommendations for Research and Innovation in Cyber-Physical Systems*. Steinbeis Edition, 2017, *Road2CPS: Priorities and Recommendations for Research and Innovation in Cyber-Physical Systems*, www.steinbeis-edition.de/out/pictures/media/187238_blick.pdf.

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Taisch, Marco, et al. *SCorPiuS: Future Trends and Research Priorities for CPS in Manufacturing*. 2017, *SCorPiuS: Future Trends and Research Priorities for CPS in Manufacturing*, scorpius-project.eu/sites/scorpius.drupal.pulsartecnalia.com/files/documents/sCorPiuS_D3_3_Final%20roadmap_whitepaper_v1.0.pdf.

Thompson, Haydn, and Meike Reimann. *Platforms4CPS: Key Outcomes and Recommendations*. Steinbeis Edition, 2018, *Platforms4CPS: Key Outcomes and Recommendations*, www.steinbeis-edition.de/out/pictures/media/202054_blick.pdf.

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12 Versions

D1.2 Report on industrial digitalisation roadmap gaps identification (interim version)	
Version - Date	**Comments & Recommendations**
V1 – 15.03.2019	D1.2 initial version with table of content
V2 – 30.03.2019	Compiling relevant inputs from D1.1 (preliminary gap analysis)
V3 – 12.04.2019	D1.2 draft version with templates for individual roadmap gap analysis
V4 – 20.04.2019	D1.2 draft version with some individual roadmaps gap analysis
V5 – 26.04.2019	D1.2 draft version with cross-roadmap analysis and recommendations, Deliverable updated with final 'special topics'
V6 – 30.04.2019	D1.2 consolidated interim version
V7 – 27.09.2019	Deliverable updated with outcomes from Collaboration Meeting, creation of gaps matrix
V8 – 18.10.2019	Deliverable updated with results from D1.1 and related analysis of gaps, updated with results from interviews
V9 – 29.10.2019	Deliverable updated with comments from the consortium
V10 – 30.04.2019	Deliverable submitted to the EC

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