D 4.2
Cross-cutting aspects implications to required skills

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Abbreviations and acronyms

TERMS, ABBREVIATIONS AND ACRONYMS	
CA	Consortium agreement
CE	Circular economy
CF	Connected Factories
CO	Coordinator
CPS	Cyberphysical systems
DoA	Description of Action
DPO	Data Protection Officer
EB	Executive Board
EC	European Commission
EEA	European Environment Agency
EFFRA	European Factories of the Future Research Association
PSS	Product service systems
GA	Grant Agreement / General Assembly
IaaS	Infrastructure as a Service
ICT	Information and Communication Technologies
IDSA	International Data Spaces Association
IT	Information Technologies
KETs	Key Enabling Technologies
OEMs	Original equipment manufacturer
ORDP	Open Research Data Pilot
PaaS	Platform as a Service
QM	Quality Manager

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QMP	Quality Management Plan
R&I	Research and Innovation
SaaS	Software as a Service
SMEs	Small and Medium Size Enterprises
SyGMa	System for Grant Management
WEF	World Economic Forum
WP	Work package
WPL	Work Package Leader

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Executive summary

This deliverable is part of the activities conducted within the project Connected Factories 2.0 (CF2). The CF2 project is organized around three broad lines of activity.

- The project explores **pathways** to the digital integration and interoperability of manufacturing systems and processes and the benefits this will bring.
- Connected Factories creates insights into **important cross-cutting factors and key enablers**.
- Connected Factories associates **projects and project results, use cases and demonstrators** to the pathways and the cross-cutting factors.

This deliverable addresses the second task by exploring important cross cutting factors and the new skills that such factors will demand. It aims to provide a reflection on the kinds of skills might be required dues to cross cutting factors including new business models, new standards and interoperability, legal issues, circular economy and systems integration. This report is organised as follows: the introduction places the report in the context of the Connected factories and the approach followed to explore the new skills requirements. Section 2 addresses new skill demands due to the advent of new business models in industrial activities. Section 3 looks into the likely new skills demands that the consideration of the implementation of the circular economy will have in manufacturing operations. Section 4 regards the likely new skills requirements due to the need of achieving interoperability across digitalised manufacturing systems and machinery as well as the arrival and harmonisation of new standards. Section 5 looks into the skills required for emerging legal aspects in the operation of Connected Factories. Section 6 looks into the fact that the previous cross cutting issues require to be integrated into a common operational logic. This requires skills on systems thinking and thus systems engineering comes as a new skills requirement for Connected Factories. The last section offers preliminary conclusions from the analysis of the insights generated across the report.

Major conclusions include:
The number of new skills requirements identified track back to some of the basic knowledge of the general and specific purposes enabling connected factories. In turn, the number of new skills requirements taken within each of the cross factors considered amount to a large number of new skills requirements. A preliminary cross analysis of the listed skills requirements identified indicates a great deal of complementarities and overlaps. This is due for the close co-evolution of the cross-cutting factors considered in the analysis. This means that with the appropriate agreement on terminology used in the different epistemological fields of expertise addressed it would be possible to reach an agreement on a limited number of key critical skills requirements. Such agreement could be one of the next steps to be conducted in the next task of work package 4 (task 4.3).

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1 Introduction

This deliverable is part of the activities conducted within the project Connected Factories 2.0 (CF2). The Connected Factories project establishes a structured overview of available and upcoming technological approaches and best practices with regard to the digitalisation of manufacturing. The project identifies present and future needs, as well as challenges, of the manufacturing industries. The CF2 project is organized around three broad lines of activity.

- The project explores **pathways** to the digital integration and interoperability of manufacturing systems and processes and the benefits this will bring.
- Connected Factories creates insights into **important cross-cutting factors and key enablers**.
- Connected Factories associates **projects and project results, use cases and demonstrators** to the pathways and the cross-cutting factors.

The specific works across work packages addresses issues in five evolution pathways (see figure 1) and a number of cross cutting factors and enablers that affect the pathways evolution. Such cross-cutting factors include: New business models, legal issues and contract agreements, cybersecurity, standardization, interoperability and circular economy.

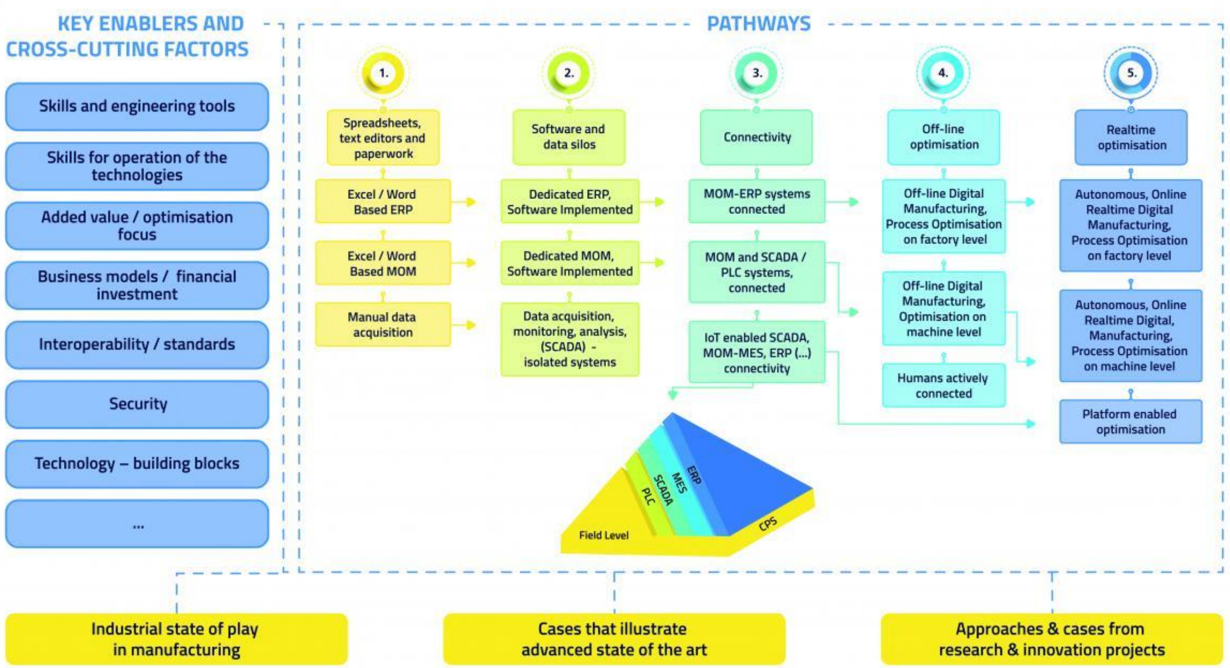

Figure 1 Connected factories project work streams

The work reported here belongs to work package four where the project Connected Factories addresses the new skills requirements in a number of tasks:

- Task 4.1 Identification of emerging skills and job requirements
- Task 4.2 Cross-cutting aspects implications to required skills
- Task 4.3 Knowledge delivery mechanisms towards a knowledge-intensive industrial workforce

This deliverable corresponds the second task (4.2) and aimed to explore important cross cutting factors and key enables affecting the deployment of CF2 across industry. Task 4.2 reflects upon the likely skills requirements that arise from by the cross-cutting factors that the implementation pathways Connected Factories is facing (See Figure 1 above). This reflection builds upon the findings of WP1 and in the findings of WP4 task 4.1.[3] As this report complements the findings and work of Task 4.1 where skills requirements for cybersecurity was already covered, such topic is not covered here. In addition, the topic of Systems Integration" was identified in Task 4.1 as a cross cutting factor but was not explored. Such topic is covered in section 6 in this report.

Cross-cutting factors are topics that affect all aspects of a programme (i.e. cut across) and therefore need special attention. They should be integrated into all stages of programmes and projects, important curriculum content which is to be covered across subjects (or disciplines or learning areas), rather than being taught and learned in a particular subject. Cross-cutting themes are additional issues or areas that intersect with the main project or can be easily integrated into the project without losing focus of the main goal. Figure 2 below shows the overall approach followed in the exploration of skill requirements demanded by the cross-cutting factors. From left to right the logic of the exploration of skills requirements stems from the technologies that enable the formation of the technology pathways that define connected factories. These include amongst others, cloud technologies, robotics, cybersecurity, artificial intelligence, cyber-physical-systems (CPS), augmented reality, simulation and digital twins. As mentioned above, the skills and competences requirements that arise from these technologies were addressed in D4.1.

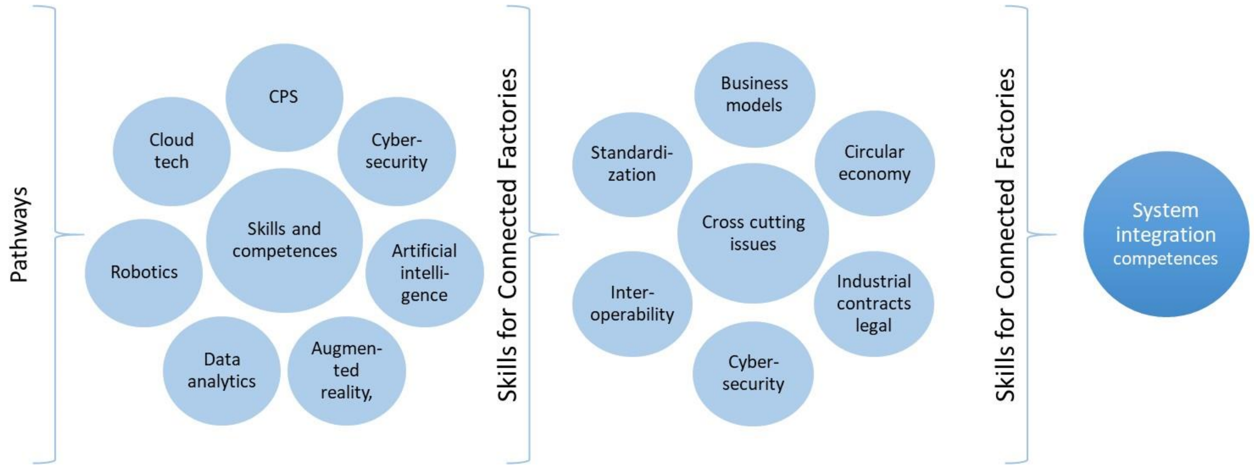

Figure 2 Logic of cross cutting issues analysis and integration competences

This report offers an early reflexion on the likely requirements that would need to be meet by the digitalisation of manufacturing businesses. In this sense, its insights are addressed to policy makers, company's strategy and human resources planning departments, research and technology organisations and education organisations. In this report the skill requirements identified pertain exclusively to introduction and usage of new digital technologies in manufacturing organisations. It is very likely that such skill requirements in manufacturing companies will have demands of new skills in other type of organisations (government agencies supporting industry, Research and technology organisations and universities for

[3] WP1. Key enablers and cross-cutting factors; WP4. Skills and transfer of knowledge; Task 4.1 Identification of emerging skills and job requirements

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example) would require to match such demand. These additional requirements are not addressed in this report.

In turn the articulation and implantation of such enabling technology generate a number of cross cutting issues that demand new knowledge and skills to be addressed. These are shown in the middle part of the figure 2. In particular, issues like new business models, circular economy and legal issues arising from contracts definition and liabilities as well as privacy and data security generate new knowledge demands. In the following sections these cross-cutting issues are addressed and a reflection on the likely skills needs is done. The reflection finds a summary with the consideration that systems thinking is not only common to all cross cutting issues but also in itself systems thinking and systems engineering is a critical skill requirement to enable the articulation of all technological, human and natural aspects associated with the implementation and upscaling of connected factories across European industry. The rest of the document is organised as follows, section 2 addresses new skill demands due to the advent of new business models in industrial activities. Section 3 looks into the likely new skills demands that the consideration of the implementation of the circular economy will have in manufacturing operations. Section 4 regards the likely new skills requirements due to the need of achieving interoperability across digitalised manufacturing systems and machinery as well as the arrival and harmonisation of new standards. Section 5 looks into the skills that emerging legal aspect that industrial agreements will require. Section 6 looks into the fact that the previous cross cutting issues require to be integrated into a common operational logic. The integration challenge requires systems thinking and thus systems engineering comes as a requirement to make Connected Factories successful.

2 Skills requirements due to new business models in manufacturing

Implementation of digital technologies in manufacturing companies is very much related with the renewal of their business models, or digitalization is seen as a means to implement the business model at hand. The purpose of the section is to review and understand the prevailing and future business models[4] that are relevant to manufacturing in order to understand their linkage to other cross-cutting factors and skill gaps.
Thus, the business model is connected to companies' current position in value chains and therefore understanding the broader change in manufacturing industry networks is important. In short, a business model describes, in a holistic manner, the logical connections and the way in which a company generates value for its customers. *A company can operate several business models at the same time*.

In traditional manufacturing network – i.e., not yet adopting I4.0 innovations – the operations of suppliers, lead producers (such as OEMs) and customers are seen as independent sequential tasks, which form a value chain. Already since the 1990s, however, this pattern has been changing and the theoretical discussion has emphasised the transfer from value chains to value networks. The trend among customers, lead producers (OEMs), and suppliers seems to be to engage in *forward transfer* in their value chains. This means that customers, lead producers or OEMs outsource manufacturing (give up earlier value chain phases), and their suppliers have increased services (add later value chain phases and give up some of the earlier phases). Concurrently, the interpretation of value has changed, and the intangible aspects of value added have

[4] A business model describes the rationale of how an organization creates, delivers, and captures value, in economic, social, cultural or other terms. Business model can be seen as an integrating element between strategy and operations.

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emphasized. Especially when considering product-service systems this dimension of intangible assets becomes remarkable.

Interdependency of operations and co-creation between the actors in a value chain have been emphasized from several theoretical viewpoints, such as services and data business. Furthermore, digitalisation of manufacturing networks has enhanced and enabled the change in roles as well as transparency in networks. Adoption of technologies also indicate evolutions regarding business models and on the other hand, business models typically cause challenges or requirements to the technologies. As an example, circular economy (CE) business models pose requirements to digital platforms in terms of transparency in the value chain or to application interfaces to enable industrial symbiosis. In particular, CE business models will be analysed including network approaches integrating both upstream and downstream dimensions along the overall product life cycle (closed-loop supply chain, remanufacturing, recycling, and other activities).

These future business models include examples of the following: cloud-based business models, platform-based business, product-service models, manufacturing as a service as well as business models supporting the transition towards sustainable manufacturing industry. Furthermore, strategic perspectives and cost- and benefit-sharing between actors will be payed attention to, i.e., different earning logics such as renting, payment according to performance, use, profit, or availability.

The benefits and difficulties of adopting new business models enabled by digitalisation and circular economy need to be analysed further. Therefore, commonalities and differences in the digitalization process of different types of companies in different markets and different sectors should be investigated in order to better understand the skill gaps.[5]

2.1 Context of Business models enabled by or enabling Connected Factories

Within the Connected Factoriesproject, especially the task 1.1 has deepened and actualised the insight in the role of business models for digitalised manufacturing and in particular in relation to the deployment of digital manufacturing platforms and CE business models. The novel business models can be categorised to three main groups: Product service systems (PSS), Data-based business and Circular/Sustainable Manufacturing.

Product service systems refer to integration of physical product with a service model. A service model is the way that a company offers intangible value to its customers. This added value can be understood as a process of increasing the perceived value of the product in the eyes of the consumers/customers. It is known as the service value proposition.

Data-based business highlights the data enabled service offerings. Different *XaaS* concepts describe broad category of service models within data-based business, which offer customers product delivery and payment options that allow them to purchase access to products as a service. The most common ones include three general cloud-computing models: Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS). Nowadays, organisations such as International Data Spaces Association (IDSA) are encouraging the creation of new business models for new products and services grounded in data spaces and

[55] As for the other key enablers and crosscutting factors, there is a section on Business models in the structured wiki of the EFFRA Innovation Portal. Based on the analyses, the portal will be enriched with a number of new examples of business model change enabled by digital transformation.

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data sovereignty. Data spaces are the key to this future, supporting the creation, promotion and expansion of data-driven markets with new business opportunities and strategic roles. However, when it comes to implementing data spaces, market participants are facing a chicken and egg problem – customers want to see products before they buy, and providers need customers for funding and feedback to develop these products in the first place.[6]

Sustainable manufacturing (including Circular economy) requires the implementation and upscaling of sustainable and/or circular business models on a wide scale. Meeting circular economy goals (e.g. reuse, repair, recycling) requires innovation in the type of business model used (e.g. moving from sales to leasing), technological innovation (new technologies) and social innovation (new ways of interacting or connecting business and people).[7] Similarly to data-based business, also sustainable manufacturing is boosted by several public actors. The European Environment Agency (EEA) is one example of such organisations, it is an agency of the European Union, who aims to support sustainable development. EEA has been working on an analytical framework for enabling circular business models in Europe. As will be mentioned in Section 3 bellow, the circular economy has become a priority policy topic in Europe (EC, 2015, 2020) and is a key objective of the European Green Deal. There is increasing interest in the potential for altering traditional business models to enable materials and products to be reused and remain in the economy for as long as possible.

2.2 Reflection on the skills needed to develop and implement new business models in CF

This sub-section focuses on the entrepreneurial competences needed for the renewal and development of current business models. To some extent the main attention is given to the management requirements of the new business models. In addition, competences related to enabling technologies are also taken into account.

Related to business models, a series of business skills have been appearing for years that, although traditional, have been maintained as essential until today, such as **Financial management** skills**; Marketing, sales and customer service** skills**; Communication and negotiation** skills**; Leadership** skills**; Problem solving** skills; or **Networking** skills**.** All those are key human skills, which are related with high level positions in companies.

However, today some skills are emerging, that have somehow had to be reinvented and getting more and more relevant now. Considering the speed at which new technologies are being developed and at worldwide markets work, skills such as **Business model innovation** or **Business opportunities detection**, are essential for today's CF business models.[8]

Business model innovation is really important in the emerging CF business models, both for data-driven models and in the circular economy. In fact, circular business model innovation could involve the development of a completely new business model, or the introduction of a business model that is new to the company, even if it is considered quite common in other companies or sectors. Circular business model innovation should not be considered independently from related technological and social innovations (such

[6] https://internationaldataspaces.org/wp-content/uploads/IDSA-Position-Paper-New-Business-Models-sneak-preview-version.pdf
[7] https://www.eea.europa.eu/publications/a-framework-for-enabling-circular
[8] https://www.eea.europa.eu/publications/a-framework-for-enabling-circular

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as data sovereignty and data spaces), which are closely interrelated. This implies that **innovation skills** such as: Capacity to **innovate and creativity**, ability to **diversify the business area** or ability to **identify and exploit new business opportunities** are needed within the company's staff. In addition, in some ways, traditional skills such as Leadership Skills or Management Skills are still relevant alongside other more current skills such as the Innovation Skills.[9] But also the manufacturing digitisation process makes it mandatory for **managers** to acquire digital skills to manage the new **disruptive businesses**, such as Information Technologies (IT) and BigData knowledge, Connectivity options (5G, Cloud technology, Dataspaces) or IoT equipment, in order to be able to improve business activities.

For example, according to sustainable manufacturing, CE models based on repurposing materials are also appearing during the last years. This type of models needs some requirements regarding production and storage space. But also need specific skills or skilled staff and equipment. It is therefore essential for companies in this field to have or acquire technical skills (quality testing, etc.); business management skills (feasibility, risk assessment and market identification); as well as financial and legal knowledge.

2.3 Identified skills gaps

In a constantly changing business environment **strategic foresight**[10] is of utmost importance for companies looking for business renewal through sustainability driven growth and aiming to more proactively understand the changes ahead. It is an approach of strategic management for companies to strategically adapt to the changes ahead, and to proactively shape their environment. Research has shown that systematic corporate foresight can significantly impact the growth and profitability of companies. Thus, this is an area in which several manufacturing industry SMEs have significant skill gaps, whereas even strategic management may be an area which is not systematically considered within the organisation. In other words, it is something that still quite often occurs through the entrepreneurs' own sense-making process.

Therefore, this section investigates the needed skills and competencies in the context of three identified business models (product-service systems, data-based business and circular/sustainable manufacturing) in CF. The analysis is performed on a framework that combines the identified future industry technologies (provided in D4.1) and the corresponding skills required to support the industry of the future. When possible, examples of transformation from manufacturing driven business towards innovation driven service business will be highlighted. The new skills requirements are likely to arise from three type of new business models reorganising the logic of manufacturing operations, these being:

- Product service systems
- Data-based business
- Circular/sustainable manufacturing

These are briefly outlined below.

[9] Sousa, M. J., & Rocha, Á. (2019). Skills for disruptive digital business. *Journal of Business Research*, *94*, 257-263.
[10] The idea is that looking into the future form of the companies business model that affected/enabled by digitalisation serves in principle as "strategic foresight".

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2.3.1 Product service systems

Product service systems refer to integration of physical product with a service model. Here the core challenge is **a transformation from product-centric thinking and operation model towards organisation structure that considers the customer value as a driving force**. That is crucial also for business model innovation. Disruptive business model could be on the other hand providing manufacturing as a service or moving towards a service focused business starting typically from the product-life cycle services (i.e., maintenance of products). Within maintenance services the IoT technologies are at the core enabling collecting data from use-phase of products.

2.3.2 Data-based business

From the perspective of traditional management skills data-based business could provide new opportunities to internally develop of more automated operations. Thus, a typical skill gap in manufacturing industry companies are the **limited resources and competences around digital technologies**. When considering the data-based service offerings different XaaS concepts could provide new opportunities. Thus, this is typically something where new partners are needed and more typically, manufacturing SMEs operate as collaborators on platforms provided by their customers. To move towards disruptive business opportunities manufacturing companies need deeper understanding on intangible value dimensions. In other words, the focus must be changed from production to customer value and digitally enabled services.

2.3.3 Sustainable manufacturing

Sustainable manufacturing (including Circular economy) always requires a network-level transparency of production and product use to implement and upscale sustainable and/or circular business models on a wider scale. Circular Economy business models must be developed integrating both upstream and downstream dimensions considering the entire life cycle of a product (e.g., closed-loop supply chain, remanufacturing, recycling, etc.). Therefore, meeting circular economy opportunities (e.g., reuse, repair and recycling) requires skills for **building new partnerships that enable novel value circles**. Here understanding the multi-stakeholder value co-creation is vital. The disruptive business could be based on an innovation in the type of business model used (e.g., moving from sales to leasing), technological innovation (new technologies) and social innovation (new ways of interacting or connecting business and people).

The table 1 provides a summary of the skills required in three different models.

Table 1. *Table 1 Matrix of skills required.*

	Novel business models		
	Product service systems (PSS)	**Data-based business**	**Circular/Sustainable Manufacturing**
Traditional management skills	Revisiting product-centred processes	Automated operations	Transparency within supply chain
Business model innovation skills	Understanding business of customer and value added	Platform Business ecosystem	New partnerships that enable R- Strategies
Disruptive business skills	Manufacturing as a service	Platform and service based business value instead on production	Repurposing materials

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Enabling technologies	Industry 4.0 (IoT)	Cloud & ICT architecture, platform	Connectivity, Blockchain smart contracts

To sum up, the critical skill gaps are obviously linked with the companies' current level of competences and role within the value networks, i.e. how significant renewal is needed. One way to identify the gaps are different maturity models, for instance: DigiMaturity tool (vtt.fi), Indicators - Circular economy - Eurostat (europa.eu). Furthermore, the **pathways (for instance service-system, data spaces and circular economy)** developed at the CF2 project provide another approach for analyses of current state and understanding the development needs between the phases.

3 Circular economy

3.1 New manufacturing within CE

Circular Economy (CE) is the latest embodiment of sustainability in the context of business operations.[11] The CE proponents argue that to achieve sustainability economic growth must be decoupled from resource constraints. The definition of circular economy varies but usually involves reduced demand for natural resources, which can be addressed with three main mechanisms for reduced demand - creating material loops, slowing material flows (leaving materials longer in the economy) and the broadest mechanism of narrowing material flows which relates to efficient use of resources through either new production technologies or/and modified consumer behaviour.[12] In turn, such decoupling enabled by innovation will bring opportunities for business creating new ways of creating value and revenues, reducing costs, and creating legitimacy.[13] Despite such promise the willingness of business to invest in CE over the years has been rather limited.[14] Although there are some drivers like consumer awareness, new policy and regulatory developments, many barriers hamper such progress, amongst these barriers, lack of technological opportunities with a major effect in productivity have played a major role.[15]

According to the World Economic Forum (WEF)[16] the future of global manufacturing is progressing from the competitiveness to the capabilities stage. Competitiveness relies on efficiency-driven production, focused on improving comparative advantages (factors such as resource availability and labour costs compared with other nations) for example through investment, policy and infrastructure. Hence there are potential improvements that fall within the design, production and distribution of higher value products (1), supplementary changes in services and activities along the value chain (2) and processes related to fabrication and distribution (3). The key factor that will support this change is **innovation** that has to be

[11] Other concepts used in the literature and in policy reports in the recent past include cleaner production, eco-innovation, sustainable innovation, etc,

[12] Kirchherr, J., Piscicelli, L., Bour, R., Kostense-Smit, E., Muller, J., Huibrechtse-Truijens, A., & Hekkert, M. (2018). Barriers to the circular economy: evidence from the European Union (EU). *Ecological Economics*, *150*, 264-272.

[13] Manninen, Kaisa, Sirkka Koskela, Riina Antikainen, Nancy M. P. Bocken, Helena Dahlbo, and Anna Aminoff. 2018. "Do Circular Economy Business Models Capture Intended Environmental Value Propositions?" *Journal of Cleaner Production* 171: 413–422.

[14] Hartley, K., van Santen, R., & Kirchherr, J. (2020). Policies for transitioning towards a circular economy: Expectations from the European Union (EU). *Resources, Conservation and Recycling*, *155*, 104634.

[15] Kirchherr et al., 2018, op.cit.

[16] https://www.ellenmacarthurfoundation.org/resources/apply/circulytics-measuring-circularity

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applied to all stages of the value chain in order to be overall effective. Innovation creates also high potential for the future industry to adapt to the concepts of Circular Economy that requires **advanced products, processes and systems**. Additionally, there is a global trend of the manufacturing industry that complies well within the concepts of CE, to progress towards **servitisation** by increasing the provision of value adding services to their products while at the same time focus in advanced manufacturing, as a tool to growth. Now is well accepted that technologies of general purpose enabling the digitalization of industry are also enabling the Circular Economy.[17,18]

Among other technologies that will dominate the future of manufacturing, McKinsey[19] has highlighted the **automation of knowledge work** that based on advances in artificial intelligence, machine learning and natural user interfaces alongside with sophisticated data analytics tools can augment employees with their work in order to accomplish manufacturing related tasks through the entire value chain. **Augmented and Virtual Reality** are vivid examples of assistive technologies that promote efficiency, safety and of zero-defect product manufacturing. The **internet of things** is a key technology of the future industry, where smart sensors and actuators connect machines with the digital world that allow monitoring and control of the production processes and flow of products. **Advanced robot solutions** that are gaining enhanced intelligence, thanks to accelerating advancements in machine vision, artificial intelligence, machine-to-machine communication, sensors and actuators will dominate the automated production. These robots will offer a more intuitive programming platform that will interact with the working force. They can be more compact and adaptable, making it possible to deploy them safely alongside workers. As a result, digital technologies, automation and connectivity are the driving forces of the future industry towards the materializing the concept of the Smart factory and Industry 4.0.

Among others, a key advanced technology that supports the concepts of the Circular Economy is the combination of **Simulation** and **Additive Manufacturing (3D printing)**, which offer design freedom, cloud- and community-based personalized design, faster product development cycle, low startup costs for production, on-demand production and less transport and logistics.[20] The sustainability and recyclability of materials for 3D printing has been highlighted as a key research area to accelerate its diffusion.[21]
On an effort to forecast the future of jobs, the World Economic Forum has identified a list of technological drivers that will change the future. Table 2 below lists three groups of knowledge areas and practices that are considered as enabling technologies that will support the deployment of connected factories within the context of the Circular Economy. The provided definition for each enabling technology sources from the report published from the WEF and includes additional information related to the concepts of the CE. The three broad categories proposed by the ActionPlanT project[22] that worked on building the ICT-enabled manufacturing vision are listed below are investigated in terms of the skillsets required to support the circularity concepts:

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[17] Romero, C. A. T., Castro, D. F., Ortiz, J. H., Khalaf, O. I., and Vargas, M. A. (2021). Synergy between Circular Economy and Industry 4.0: A Literature Review. *Sustainability*, *13*(8), 43-31.

[18] Rosa, P., Sassanelli, C., Urbinati, A., Chiaroni, D., & Terzi, S. (2020). Assessing relations between Circular Economy and Industry 4.0: a systematic literature review. International Journal of Production Research, 58(6), 1662-1687. DOI: 10.1080/00207543.2019.1680896

[19] Disruptive technologies: Advances that will transform life, business, and the global economy, McKinsey 2013

[20] 3D printing with biomaterials https://www.hva.nl/binaries/content/assets/subsites/urban-technology/3d_printing-with-biomaterials_web.pdf

[21] Circular Economy Innovation Project, Feasibility of reusing Waste Electrical and Electronic Equipment (WEEE) for 3D printing, https://www.ellenmacarthurfoundation.org/assets/downloads/schmidt/CEIP-formatted-Article-Final-Phil-Brown.pdf

[22] http://cordis.europa.eu/project/rcn/95333_en.html

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- On-Demand delivery of customized products through a network of manufacturing partners
- Innovative new product and process technologies
- Sustainable and of optimal quality products and services

Table 2 Skills requirements of Circular Economy practices at the company level

CE Practices	Skills requirements to support CE practices
On-demand customized products	• Rapid prototyping of new manufacturing systems • Reconfiguration of existing manufacturing systems • Simulation the production so as to introduce AR and VR. • Management of frequent changes of product design, production processes and manufacturing systems • Design and operation of self-optimizing systems and control systems • Planning, operation and management of a network of plants and suppliers • Designing a reverse supply chain
Innovative new products and process technologies	• Design and operation of flexible, high precision production and test equipment • Design and operation of new processes leveraging advanced, graded, bio-, nano- or hazardous materials. • Managing of innovation life cycle • Identifying, protecting and monetizing intellectual property • "Teaching Factory" capable of training employees for emerging manufacturing job profiles • Designing and launch of new manufacturing business models based on finance- and science-based entrepreneurial spirit • Design for reuse, remanufacturing and closed-loop recycling • Applying Life Cycle Assessment tools through the design process • Designing of material, resource and energy efficient with minimum waste and environmental footprint production methods
Sustainable and of optimal quality products and services	• Ensure the compliance of products, manufacturing processes, and aftersales services with regulatory constraints, industry best practices and company rules. • Design and execution of preventative maintenance plans and condition-based maintenance of manufacturing equipment • Optimization processes efficiency enterprise –wide. • Optimization of end to end energy consumption and other environmental costs factors of manufacturing processes. • Configuring operations management ICT systems and managing the enterprise processes in real time • Designing, simulating and executing aftersales services • Design of product collection systems for remanufacturing, reuse and recycling

Remanufacturing, reusing, recycling and maintenance are key features of the "Circular Economy System Diagram" proposed by the Ellen MacArthur Foundation.[23] The implementation of these features directly relies on enabling technologies that cover the entire value chain and life cycle of a circular product and circular process.[24] In remanufacturing the value added to the raw materials for producing a part is recycled in addition to the raw materials themselves. As such the principal components can be reused by the consumers. In some cases, the circular products have to be designed in a way that they are customizable yet

[23] https://www.ellenmacarthurfoundation.org/circular-economy/interactive-diagram

[24] Circular product and circular process are the products and manufacturing processes designed to comply with the concepts of circular economy. https://www.ellenmacarthurfoundation.org/assets/downloads/publications/Ellen-MacArthur-Foundation-Towards-the-Circular-Economy-vol.1.pdf

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re-manufacturable and designed upon product upgradability so that the "new" product can meet the demands and requirements set of another consumer. From the design point of view, the product must have a reasonably long life, and its functions should not be underpinned by a technology subject to rapid change. The product should be capable of being dismantled without excessive damage, and its normal failure modes should be repairable. Failure should leave a large fraction of the product in reusable condition through refurbishment, and the cost of labour and of replacement parts must be such that the remanufactured article, after allowing for a reasonable profit, enjoys a price advantage relative to a comparable new unit.[25] Therefore, skills and competencies related to reuse and remanufacturing are required by engineers on designing of products and manufacturing processes that comply with the concepts of circular economy.

3.2 Skills requirements: Skills needed achieve a twin transition CE and CF

This section investigates the needed skills and competencies of the workforce in order to support the EU reindustrialization within the context of the circular economy. The analysis is performed on a framework that combines the identified future industry technologies (provided in D4.1) and the corresponding skills required to support the industry of the future together with the concepts of the Circular Economy.

The European Commission with the communication to the European Parliament "A new skills agenda for Europe" has pointed out the skill requirements towards strengthening the human capital and supporting the economy.[26] It is reported that there does exist a variation between current and future skills needs across different sectors of the economy, since new sectors emerge or radically change, mainly but not exclusively driven by technological developments. The transformation in the sectors is driven by innovative action plans that include the transition to a circular economy alongside with Key Enabling Technologies (KETs), such as nanotechnology, artificial intelligence, robotics and more recently big data analytics. Access to qualified human capital that will be able to support this transition is key for enabling competitiveness and innovation, since the availability of high-end skills is also a critical element for investment decisions. In order to support the transition to a Circular Economy, all engaged actors shall transform their current way of thinking to a circular way of thinking that goes hand in hand with systems thinking.

Within Circular Economy all associated elements are turning circular, e.g. circular product, circular process, circular business model etc. This means that designing products, manufacturing processes, supply chains and manufacturing systems should be seen from the system-holistic point of view. Here we provide a preliminary basis that will assist with the identification of the currently available human capital and identify any potential gaps. In this direction the key elements that influence the formulation of the skills' needs are:

- Reuse / Remanufacturing / Recycling
- Circular design of product / process system
- Innovative new products and process technologies
- Life Cycle Assessment of products
- Sustainable and of optimal quality products and services

[25] Remanufacturing Towards a More Sustainable Future, Electronics-enabled Products Knowledge-transfer Network, http://www.lboro.ac.uk/microsites/mechman/research/ipm-ktn/pdf/Technology_review/remanufacturing-towards-a-more-sustainable-future.pdf

[26] See http://ec.europa.eu/social/main.jsp?catId=1223

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- On-demand customized products
- Artificial intelligence and machine learning
- Automation and robotics
- New materials technologies

Depending on the job type, the workforce shall be equipped with multi-disciplinary skills that covers different aspects of the Science and Technology, Business and Innovation, Human and Society, Environmental responsibility and Policy and Finance. The sixth building block namely Education & Training is the means of skill and competence development. In order to facilitate with the identification of the skills' needs that will support the industries and SME's to invest towards the Circular Economy and further investigate the present availability and potential gaps in qualified human capital, the following generalized skill categories will be used:

Content skills are related to the job-specific skills and include those that relate specifically to the line of work.

Process skills are used to manage and modify actions in the completing of daily living tasks, such as pacing oneself, choosing and using appropriate tools to complete a task, or organizing a task into a logical sequence for successful completion (use data to construct reasonable explanations, communicate investigations and explanations, understand scientific inquiry).

Resource management skills are important to assure that a company's resources are used in the most efficient way possible.

Complex problem-solving skills refer to developed capacities used to solve novel, ill-defined problems in complex, real-world settings.

Social skills are the skills we use to communicate and interact with each other, both verbally and non-verbally, through gestures, body language and our personal appearance.

Technical skills are the knowledge and abilities needed to accomplish mathematical, engineering, scientific or computer-related duties, as well as other specific tasks relating to technology.

Systems skills are used from an individual to determine how a system should work and how changes in conditions, operations and the environment will affect outcomes.

It is foreseen that the workforce that will support the manufacturing sector and the circular economy, shall be equipped with all the above skill categories. However, depending on the job type there are certain skills and competencies that are of more relevance compared to others. Apart from technical and content skills that are relevant at all levels, these shall be complemented with strong generic skills, particularly in terms of social skills, problem solving skills, process skills and resource management skills appropriate to the level of the work. These skills are essential enablers for manufacturing excellence. They are also essential in other contexts, such as where contact with customers or suppliers is required, in product development, when working with regulatory bodies, or when seeking to influence investment decisions by parent companies. Nevertheless, since circular economy requires systems thinking, **human capital with systems skills is a key enabling condition** that will allow for the EU industry investment within the circular economy context.

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A circular approach to product design has an immediate reflection to all aspects associated with the product value chain. The imposed requirements should include design for remanufacturing and reuse without compromising structural integrity or function. This has an immediate impact to the material selection, since the associated materials shall be recyclable, allowing for product customization and can be used in (re)manufacturing processes that are energy, resource and material efficient. In addition, circularity requirements demand modular, design for disassembly, design to last, and production process efficiencies that 19minimize waste. Customizable products that are designed to be reused and remanufactured require 19modular design, such that the problematic elements can easily be isolated and repaired/replaced accordingly. Therefore, manufacturers have to decide what enduring materials should be used to form the core of a 19 customizable product—i.e., the skeleton that lives on while modules and 19customizable add-ons are replaced. Design for modularity methods based on assistive Virtual Reality technologies together with flexible assembly techniques, that allow for part dismounting, are well established in the industry and be used to make products easier to disassemble.

As a result, implementation of the concepts of CE requires **advanced technical skills, complex problem-solving skills, process skills and most importantly systems skills** that are complementary to the ones already available in the workforce. In this direction, **specialized knowledge** is essential in order to close the loop on part/component remanufacturing and product refurbishment. Other circular aspects such as collection, disassembly, integration into the remanufacturing process, and getting products out to users all require **specialized skills and process know-how**. The use of **Lifecycle Assessment (LCA) tools** that enable producers and designers to assess the life costs of products and processes and subsequently manage material choices for ecological optimizations; features that are completely aligned with the concepts of the circular economy. Therefore, such **specialized knowledge** to incorporate LCA methods and develop intuitive way of thinking is required within the circular product/process design.

Besides the aforementioned technical skills, to optimize product designs and materials for production in a repeated framework within closed loops and in accordance to the circularity requirements, the core competency of the related workforce is **thinking in terms of systems** and being able to see 'the wood and the trees'. Systems thinking is the process of understanding how component parts of a system can best be understood in the context of relationships with each other and other systems, rather than in isolation. Systems thinking focuses on cyclical rather than linear cause and effect. Hence, systems skills are used from an individual to determine how a system should work and how changes in conditions, operations and the environment will affect outcomes. Within the context of the circular economy, systems skills are at most important and as these are applied broadly, taking into account the system dynamics between businesses, people or planet, the manner in which they are linked and respond to each other.

As a summary and implications of considering the circular economy in manufacturing operations. From the above it seems clear that there is, at least partially, a synergy between the circular economy and industrial digitalization. To a large extent many of the features of the ongoing industrial digitalization enable aspects of the circular economy. The low hanging fruit would be the immediate gaining of efficiencies in the reduction of inputs, materials and energy usage that are implicit in the adoption of new digital technologies in manufacturing operation. The challenge for companies adopting the circular economy is advancing the current thinking along the circular economy logic and follow up on reorganizing in practice beyond efficiency gains towards materials substitution, redesign for longer product life, product-services systems and remanufacturing. These actions require a new logic that is not implicit in industrial digitalization and connected factories.

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4 Interoperability and standards

4.1 Context of interoperability and standards in CF

As described in D1.2, **Interoperability** has very different meanings for different persons according to their position in the manufacturing company. Interoperability can be analysed from very many different perspectives like type of data, data granulometry, data frequency, data size, data repositories, communication protocols, repositories allocation, middleware, and other one can conclude that each of these aspects requires a specific analysis and probably some specific knowledge. The Reference Architecture Model Industrie 4.0 (RAMI4.0) model permits a better understanding of the concept, addressing specific skills of a human with respect to internal and external interoperability requirements (Figure 3).

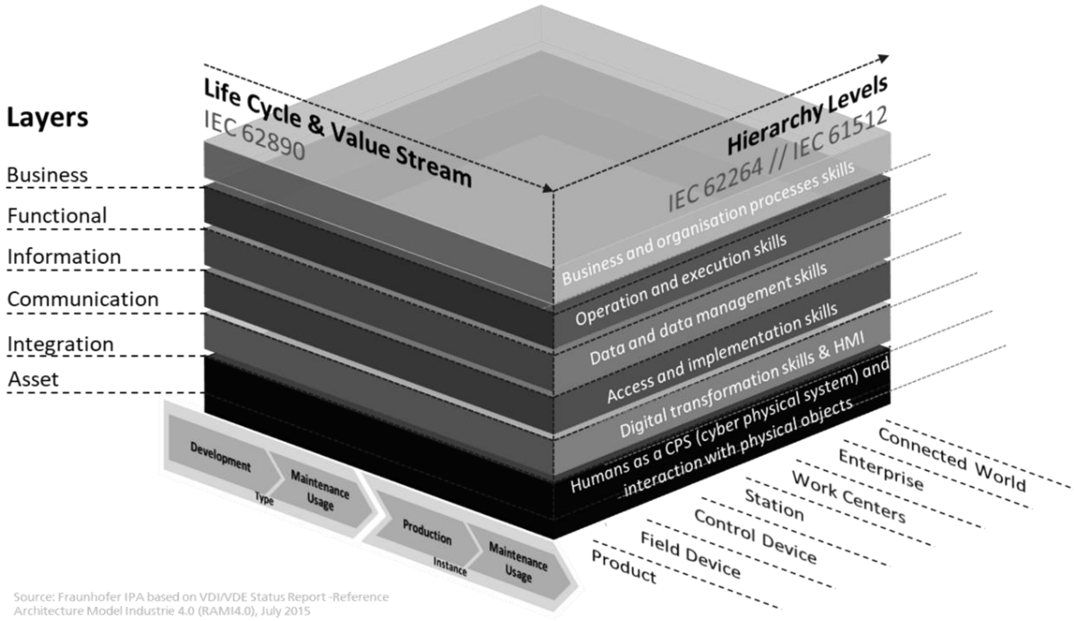

Figure 3 Human skills in context of Interoperability within the Reference Architecture Model RAMI 4.0 (Source: Fraunhofer IPA based on VDI/VDE Status Report -Reference Architecture Model Industrie 4.0 (RAMI4.0), July 2015)

Standardization in the context of digital interoperability focuses essentially on the improvement of human work, taking into account such factors as rapid technological progress (digitization, artificial intelligence), sustainability, demographic developments and the changing values in society or globalization[27]. It is becoming increasingly important to develop technological standards adapted to the latest developments in digitization and to ensure that technological developments support people in their work, such as the introduction of new technologies that affect the work of humans and their co-workers.

Within a work process, humans are entrusted with various tasks (e.g. operation of a machine, programming tasks, maintenance) as main actors in a sociotechnical system (STS). The STS recognizes the interaction between people and technology in a workplace. For the design of an ergonomic, efficient and flexible working environment and workflows in a smart factory, it is important to take into account not only the criteria for (1) feasibility and compliance with required values, (2) freedom from harm, and (3) negative

[27] https://www.din.de/de/forschung-und-innovation/themen/innovative-arbeitswelt/normungsroadmap

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*impacts, but also (4) develop human personal abilities, skills, performance (Figure 4*Figure 4 Human skills and competences for standards sociotechnical system. (Source: German Standardization Roadmap Industrie 4.0, Ed. 4)

~~*Figure 4 Human skills and competences for standards sociotechnical system. (Source: German Standardization Roadmap Industrie 4.0, Ed. 4)*~~

Human labor in value networks continues to play a central role and socio-technical aspects therefore represent a crucial requirement for the design and operation of plants. So far, socio-technical aspects have been addressed only very little or insufficiently in Industrie 4.0 standards. It is therefore now all the more important to take these into account in the new standards or to check the old standards for consistency.

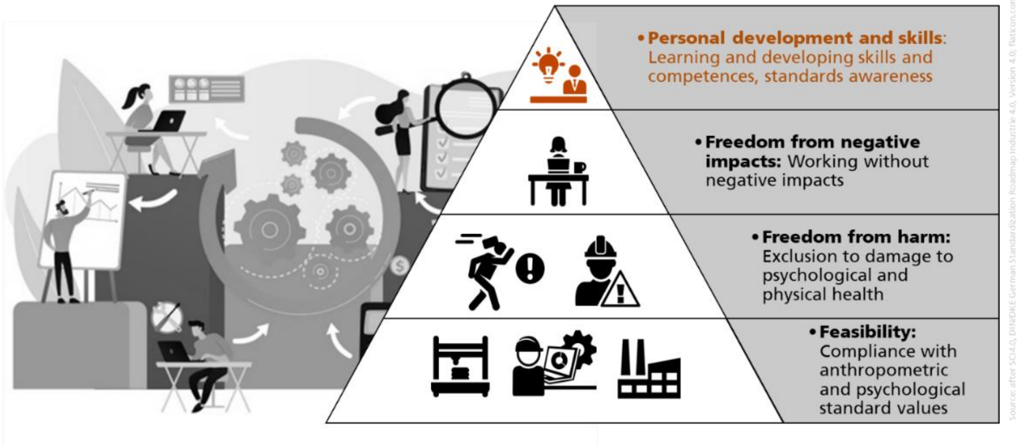

Figure 4 Human skills and competences for standards sociotechnical system. (Source: German Standardization Roadmap Industrie 4.0, Ed. 4)

The highest criterion here is that the workplace needs to be designed in such a way that it promotes the development of the individual by enabling them to learn and develop new skills. Especially, the awareness of standards and conscious handling of norms and regulations need to be developed in the STS workplace.

The common principles of ergonomics have been established by DIN EN ISO 6385[28] in the form of basic guidelines for the design of work systems. This standard is a basic ergonomic standard for work systems, on which many other standards on specific topics build up. It describes an integrated approach to the *design of work systems* in which ergonomists collaborate with others involved in the design and balance human, social, and technical requirements during the design process. The design process addresses elements of a work system such as (1) work organization, (2) tasks and activities, (3) work equipment and interfaces, and (4) work

[28] DIN EN ISO 6385: 2016-12 *Ergonomics principles in the design of work systems (ISO 6385:2016),* https://www.beuth.de/de/norm/din-en-iso-6385/250516638

environments. Workspaces and workstations that are closely connected must consider human skills needs for the implementation of technical requirements ensuring interoperability and application of standards (5).

Thus, the standard is applied to develop practical skills of humans in various positions, i.e. managers, workers and other professionals such as occupational scientists and developers who participate in the design or redesign of work systems.

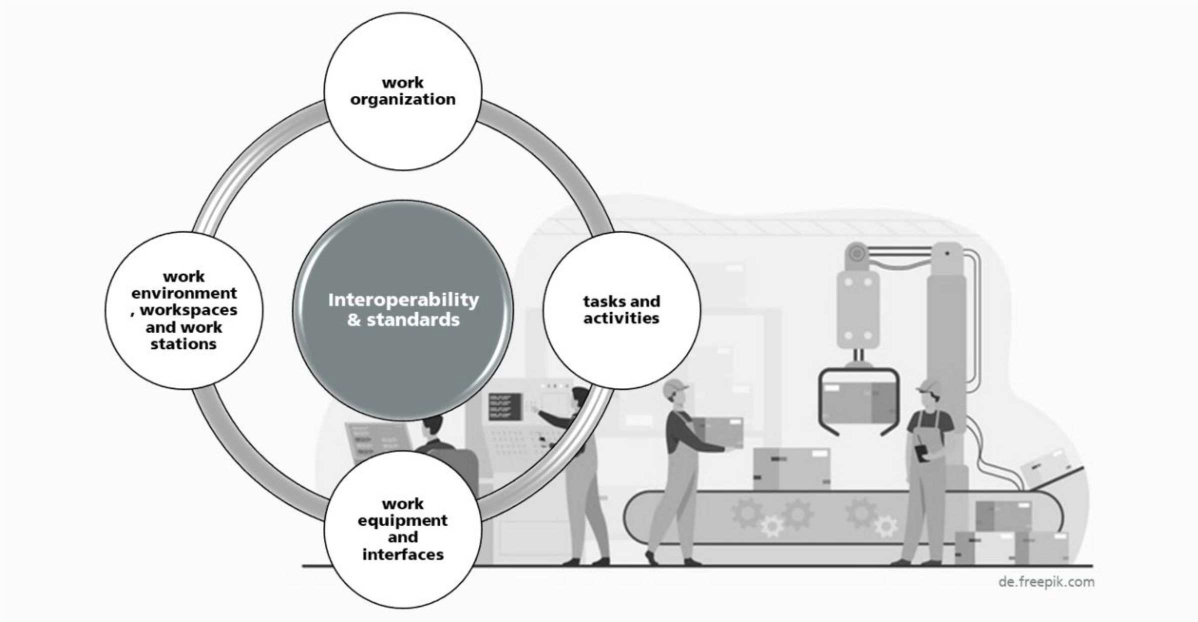

Figure 5 Common elements of a wok system in the scope of human skills and competences for interoperability and standards

Not only the design, but also the *interaction of a human with technical systems* often is important while manufacturing within a factory environment (incl. smart technologies and machinery). In this context several standards implement useful ergonomic requirements of standards, for instance:

- the Machinery Directive 2006/42/EC, 2009/127/EC[29] (with regard to machinery for pesticide application);
- DIN EN ISO 9241 series[30] (usability concepts for ergonomics of human-system interaction);
- DIN EN ISO 984 series[31] (European standards series for ergonomic requirements for the location and arrangement of displays and control actuators in order to avoid hazards associated with their use), and other.

Another important field is the design of tasks and activities, which covers such important standards in the digitization process as interoperability of assistance systems in the context of *human-machine or human-*

[29] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32006L0042
[30] DIN EN ISO 9241-11:2018-11 Ergonomics of human-system interaction - Part 11: Usability: Definitions and concepts (ISO 9241-11:2018), https://www.beuth.de/en/standard/din-en-iso-9241-11/279590417
[31] DIN EN 894-4:2010-11 Safety of machinery - Ergonomics requirements for the design of displays and control actuators - Part 4: Location and arrangement of displays and control actuators; German version EN 894-4:2010

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robot collaboration (e.g. the requirements for robot (systems) formulated by DIN ISO/TS 15066:2017 or DIN EN ISO 10218-2:2012).

Manufacturers of machines are obliged to carry out a risk assessment by which the knowledge about the design and use of machines and the experience gained from incidents (as in DIN EN ISO 12100), accidents and damage needs to be carefully compiled to evaluate the risks in all phases of the life of machines. For this purpose, DIN EN 13861[32] provides references to European and international ergonomics standards from the various relevant areas for the individual *ergonomically relevant hazards* and addresses the hazards mentioned in DIN EN ISO 12100 as far as ergonomics is concerned. The standards for the ergonomic design of machines listed in DIN EN 13861 contributes to the avoidance of numerous hazards and risks by evaluation during the design process, taking into account the intended use and expected use as well as the foreseeable misuse of the machine.

Further, the development and consideration of standards and work-related findings is not sufficient for the design of work systems and socio-technical environments. Therefore, *requirements for workplaces and work equipment* are commonly regulated by national and European law, e.g. the Directive 89/391/EEC[33] that introduces common measures to encourage improvements in the safety and health of workers at work.

Forthcoming standards in this area are motivated by the introduction of novel technologies as e.g. Artificial Intelligence, advanced learning systems or fully automated systems, and their impact on the human work environment.

Thus, with the increasing introduction of AI solutions in various areas of the working world, it is now necessary to ensure that the relevant standards are implemented. The goal in developing new standards as well as revising existing documents is to find the solutions that improve the human working environment when using AI[34]. Furthermore, human-machine and machine-machine interactions are becoming increasingly relevant through the use of AI solutions in work processes. Looking at socio-technical systems, for example, different types of contexts arise during communication, such as (in the case of human-machine interaction) the input of written voice commands or the transmission of tasks to the machine, which must first be converted into machine-readable codes. In the process, different semantic contexts emerge, which still need to be strongly specified by forthcoming standards, since smooth semantic communication between humans and machines ensures an important prerequisite for error-free, effective and efficient work and task completion.

4.2 Skills requirements

This section reflects upon the needed skills and competencies in the workforce required to support the European Union's push for increased interoperability and adoption of standards within the manufacturing domain. Surveys of companies show that the largest perceived barriers to the adoption of industrial digital

[32] DIN EN 13861:2012-01 Safety of machinery - Guidance for the application of ergonomics standards in the design of machinery, https://www.beuth.de/de/norm/din-en-13861/146078376
[33] https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=celex%3A31989L0391
[34] https://www.dke.de/de/arbeitsfelder/industry/news/normungsroadmap-arbeitswelt-publiziert

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technologies are firstly digital skills, and secondly data compatibility, highlighting the importance of skills for standards and interoperability[35].

Deliverable 4.1 identified the future technologies required for Industry 4.0 transition, and the need for horizontal and vertical system integration and interoperability is shown as a clear technological trend. However, even for other technological trends such as big data, digital twins, industrial internet of things, cybersecurity and many more – the need for enabling standards and for cross-system interoperability is essential but often understated.

Considering interoperability in general requires a vast knowledge of both Information Technology (IT) and Operational Technology (OT), combined with a detailed understanding of the system for which interoperability is required. This typically cannot be condensed into one single person and requires the cooperation of all three macro-professions (as defined in D4.1) i.e.:

- *Operators and Technicians* to understand the structures and interdependencies of systems and the requirements for how they are used.
- *Professionals and Engineers* to identify standards and ways in which interoperability can be implemented.
- *C-Level Executives and Managers* to understand what company policies and priorities should be incorporated into the chosen standards.

As such, as well as skills specific to interoperability and standards, this field also requires the more general skills of creativity, innovation, critical thinking, and - most importantly - collaboration and communication.

New digital technologies are constantly emerging at an increasingly rapid pace, and the standards which support them are also being created and adapted to new technologies. Standards bodies are producing roadmaps detailing future standards which are being prepared, or emerging areas in which standards are expected to be required. Examples include The German Institute for Standardization (DIN) and German Commission for Electrotechnical, Electronic & Information Technologies of DIN and VDE (DKE)'s roadmap for AI standards[36] and Industry 4.0 standards[37] - both of which include domains relevant to interoperability. However, even these roadmaps do not include definite timeframes or time horizons, showing the current uncertainty on when standards will be released or even when the relevant technologies will be sufficiently mature to be standardised.

This creates a critical challenge for skills in interoperability – "*Technology will only continue to progress at an accelerating pace and to be adequately prepared, workers will consistently need to learn and upskill themselves in order to keep pace with innovation*"[38]. The skills for implementing standards and

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[35] Make UK – Bouncing Back Smarter: Innovation Monitor 2020. https://www.makeuk.org/insights/reports/innovation-monitor-2020

[36] https://www.din.de/resource/blob/772610/e96c34dd6b12900ea75b460538805349/normungsroadmap-en-data.pdf

[37] https://www.din.de/resource/blob/65354/1bed7e8d800cd4712d7d1786584a7a3a/roadmap-i4-0-e-data.pdf

[38] The 2019 World Manufacturing Report: Skills for the Future of Manufacturing. https://worldmanufacturing.org/wp-content/uploads/WorldManufacturingFoundation2019-Report.pdf

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interoperability in digital manufacturing are as much about identifying applicable standards, as they are about the skills specific to the standards themselves.

Approximately two thirds of the 2030 workforce have already left the education system[39], so workers cannot be expected to know standards and interoperability skills that emerge in the next ten years. This forces a change in how we think about skills acquisition and educational programs. But it also introduces new educational partners, such as life-long professional development programmes at technical schools, colleges and universities along with asynchronous digital options such as Massive Online Open Courses (MOOCs), online learning platforms such as Coursera and Udemy, and self-directed on the internet.

The European Commission European Skills Agenda report[40] concurs with this assessment. Several of the identified actions are directly relevant to standards and interoperability:

- Action 2: Strengthening Skills Intelligence. Identifying emerging skills needs and skill gaps at regional and sectoral levels so learning opportunities can be provided. As interoperability standards continue to change, identification of gaps in the necessary skills are particularly important.
- Action 3: EU Support for Strategic National Upskilling Actions. Using skills intelligence to provide skills training for maximum strategic impact. The roadmaps provided by standards organisations such as DIN / DKE go some way towards identifying the key interoperability standards for the future. Understanding the impact these technologies will make and therefore what enabling skills should be prioritised for training and funding will accelerate the adoption of these technologies in industry and contribute to the Commission's objectives of increased uptake and deployment of standards.
- Action 5: Rolling out the European Universities Initiative and Upskilling Scientists. Bringing industry and academia together so emerging technologies and standards can be more rapidly transferred into industrial via training individuals. Technologies emerging from academia and industrial research and development present disruptive opportunities for European industrial productivity, but the skills and knowledge needs transferring to industry. A kay additional consideration here is the cooperation of academia and standards organisations so emerging technologies can be identified and standardised more rapidly.
- Action 8: Skills for Life. Developing comprehensive and high-quality adult learning systems, enabling manufacturing engineers to be learning and implementing new skills. As previously stated in this section, standards are emerging or evolving rapidly, so most users of these standards will have to learn them as part of a lifelong learning strategy.
- Action 10: A European Approach to Micro-Credentials. Enabling people to be certified in small areas (such as standards) so their self-learned skills can be trusted and verified. An additional consideration of rapidly emerging standards is that of updated and changed standards, which meet the emerging technological requirements. Micro-credentials offer a structured way of ensuring that an individual is not only trained in a standard, but in the current modern iteration of that standard.

[39] Made Smarter Review 2017
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/655570/20171027_MadeSmarter_FINAL_DIGITAL.pdf

[40] European Skills Agenda for Sustainable Competitiveness, Social Fairness, and Resilience. European Commission.
https://ec.europa.eu/social/BlobServlet?docId=22832&langId=en

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- Action 12: Improving the Enabling Framework to Unlock Member States' and Private Investment in Skills. Promoting in-house training in companies by providing financial mechanisms. More than many other areas, use of standards for interoperability enables a connected, productive ecosystem as companies become more able to collaborate without barriers. However, this requires a quorum of companies to adopt the standards to realise the benefits, and a structured approach to funding would facilitate this.

Action 12 is particularly applicable to medium-sized companies. Statistically, very small companies (1-9 employees) and very large companies (1000+ employees) are most likely to undertake in-house training to improve digital skills[41]. Smaller companies can often follow agile principles and have a clearer view of skills gaps. Larger companies have greater access to capital to fund training, and established policies for implementing it. Companies in the middle of this range can struggle to implement in-house training.

One important source of knowledge and training in the manufacturing industry are EQUIPMENT SUPPLIERS. See picture below. The knowledge and inventory capability of a company cannot be understood without the knowledge and capabilities of its suppliers.

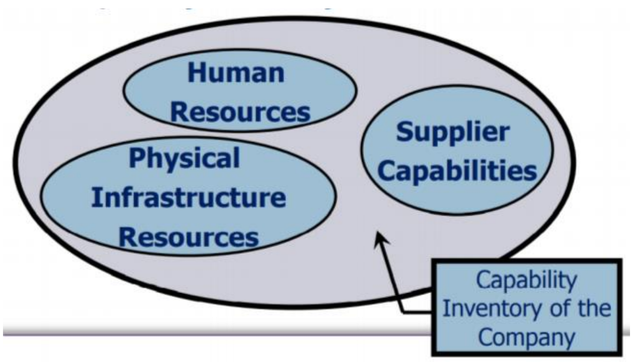

Figure 6 Transfer of specialized knowledge and capabilities suppliers

Interoperability and standards-specific skills can be classified as:

- Skills for **identifying the needs and requirements** of a manufacturing system that interoperability standards could solve. (*for example, that the standard must enable communication at a certain data rate, with a certain level of time predictability, that is compatible with certain equipment types, compliant with corporate goals etc*).
- Skills for **identifying the applicable interoperability standards**, which meet requirements. (*for example, knowing which standards bodies to search, where to find relevant information, seeking example use cases, interpreting standards etc*).
- Skills for **implementing** interoperability standards on a specified manufacturing system. (*for example, understanding what data formats to use, how to combine software packages, how to configure systems, etc*).

[41] Make UK Digital Skills for a Digital Manufacturing Future. https://www.makeuk.org/insights/reports/digital-skills-for-a-digital-manufacturing-future

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- Skills for **documenting** the implemented interoperability standards so they are maintainable. (*for example, recording which standards were used, and implementation-specific details about how they were used*).
- Skills for **evaluating** the implemented interoperability standards and **identifying gaps** to understand if the chosen standards were correct or if the chosen standards remain fit for use.
- Skills for **updating** the implemented interoperability standards so emerging developments can be incorporated, security fixes integrated, and documentation updated.

5 Connected factories legal aspects

5.1 Context of industrial agreements and legal issues in CF

An overarching question to answer before identifying new skills requirements concerns: How to develop contractual obligations in an environment that is in constant optimization and customization, and caters to hybrid business models? As the first implementation steps of CF are in their early days, impact in most areas is hard to predict.[42] Accordingly, the arising legal challenges around the factory integration of processes that are sensor-controlled, data-driven, largely self-optimizing and self-managing have to be addressed within an environment of a high connectivity and uncertainty. Data protection, liability issues and labor laws seem to be on top of the concerns agenda.[43] In addition, depending on the particular step in the industrial production process under scrutiny, as well as on the digital applications that accompany it, many other legal disciplines will play a role: technical standardization and certification frameworks; copyright and intellectual property laws; insurance law; tax law; product safety regulations; environmental laws; transport law; and national and international competition law.

An additional difficulty is introduced by the increasing use of ‘smart contracts’ or digital industrial contracts - a piece of self-enforceable software code implemented on Blockchain platforms - to control resources in production processes, to exercise access control of multiple subject-object pairs, to evaluate users’ behavior during access control, or to manage other contracts. Unlike the rationale behind classic contracting, according to which trust is put in the (legal) person of the other party to the contract, in smart contracts trust is put in the algorithms standing behind the agreement (“trustless trust”).[44] Such a process raises questions about the content of the initial agreement, its proper translation to code, and the consequences of unexpected technological or software glitches.

[42] Weber, K. Matthias, Niklas Gudowsky, and Georg Aichholzer. "Foresight and technology assessment for the Austrian parliament—Finding new ways of debating the future of industry 4.0." *Futures* 109 (2019): 240-251; Aichholzer, G., Rhomberg, W., Gudowsky, N., Saurwein, F., & Weber, M. 2015. Industry 4.0 - Background paper on the pilot project “Industry 4.0: Foresight & technology assessment on the social dimension of the next industrial revolution”. Institute of Technology Assessment, Austrian Institute of Technology (eds.) ITA-project ITA-project report Nr.: ITA-AIT-1en. Wien http://epub.oeaw.ac.at/ita/ita-projektberichte/ITA-AIT-1en.pdf.
[43] Aichholzer, ibid., p. 36.
[44] Savelyev, Alexander. "Contract law 2.0:‘Smart’contracts as the beginning of the end of classic contract law." *Information & Communications Technology Law* 26.2 (2017): 116-134.

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Overall, in the context of CF the challenges to maneuver within the boundaries of the law, and to do so with a degree of legal certainty, are significant. Reliable legal concepts and standards are the basis of trust and responsibility, which are necessary for the secure and traceable monitoring of contractually agreed information and workload sharing between machines, operators and service providers, throughout the entire production cycle in an international trade environment.[45] In order to outline where the development of concepts, standards and skills is most pressing, we first provide some more context to the following challenges:

- Data governance of corporate and personal data in an international trade environment
- Liability in a distributed production process and meaningful human control
- Human-machine teaming
- Use of smart contracts

5.1.1 Data governance

In the context of CF, data governance issues manifest themselves in a twofold manner – on the one hand there is the necessity to protect sensitive corporate data, while on the other there are concerns about the personal data of employees and customers. The networked nature of factory plants enables the exchange of design and configuration data between machines and companies. The protection against corporate espionage and the protection of domain expertise both require the establishment of solid technical and legal safeguards. The possibility to collect in detail information about how employees perform their tasks, including data on their work habits and health, pose additional data protection and labor law challenges. Further, the context of CF implies the possibility of collecting information on the usage patterns of customers,[46] which can be used for fine-tuning of internal applications but can also be re-sold to external parties. CF data governance thus raises questions not only on the protection of the parties from which the data originate, but also such on the data's economic value, the social, political and ethical implications of their usage, as well as the adequate placement of data as an asset/ product in contractual agreements.

5.1.2 Liability

The networked, 'open' nature of CF further increases the possibility of damage to equipment, products, customers, employees and assets.[47] However, its distributed production processes make it hard to attribute liability to a responsible unit, factory floor or corporate entity, and to precisely narrow down which digital application malfunctioned. How to deal with the latter is an ongoing question in national and international legal debates. This brings about not only questions of civil liability and criminal accountability in such

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[45] Weber, K. Matthias, Niklas Gudowsky, and Georg Aichholzer. "Foresight and technology assessment for the Austrian parliament—Finding new ways of debating the future of industry 4.0." *Futures* 109 (2019): 240-251.

[46] Lazarova-Molnar, Sanja, Nader Mohamed, and Jameela Al-Jaroodi. "Data analytics framework for industry 4.0: enabling collaboration for added benefits." *IET Collaborative Intelligent Manufacturing* 1.4 (2019): 117-125.

[47] Aichholzer, G., Rhomberg, W., Gudowsky, N., Saurwein, F., & Weber, M. (2015b). Industrie 4.0 – Foresight & Technikfolgenabschätzung zur gesellschaftlichen Dimension der nächsten industriellen Revolution (zusammenfassender endbericht). Bericht-Nr. ITA-AIT-2, p. 37, Wienhttp://epub.oeaw.ac.at/ita/ita-projektberichte/ITA-AIT-2.pdf.

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processes, but also of meaningful human control over self-enforcing and increasingly autonomously functioning equipment.[48] The nature of contractual relations between suppliers and clients as well as related data flow requires carefully drafted legal contract agreements with detailed descriptions of the service, product or data types transferred as well as purpose of data gathering (e.g., preventive maintenance, inventories, quality control, performance assessment, etc.). Such contracts drafting requires the close interaction of qualified lawyers with knowledge of ICT and data sciences with CF managers (at several layers of management, see RAMI model).

5.1.3 Human-machine teaming

On the intersection of questions on data governance and liability arise further ones regarding new forms of human-machine teaming, intrinsic in the constitution of the envisioned CF processes. This hybrid way of conceptualizing and organizing the work force will have an impact on labor and occupational safety law,[49] which will have to re-evaluate and adapt its tenets to a new rationale of job designs and work duties.

5.1.4 Smart contracts

Digital industrial contracts or smart contracts are a new paradigm of interaction in cyber-physical systems. They are defined by Clack et al. as "an agreement whose execution is both automatable and enforceable. Automatable by computer, although some parts may require human input and control. Enforceable by either legal enforcement of rights and obligations or tamper-proof execution."[50] The latter definition encompasses both smart contract code, as well as smart legal contracts as defined by Stark (2016).[51]

When employing digital contracts, an essential pre-requisite for enforcement is to have the agreed quality of services between the business parties digitized for purposes of compliance monitoring, verification, and initiation of actions, in case contracts are violated.[52] The current state of the industry, however, has not reached such a level of digitalization yet. Accordingly, the feasibility of real-time reporting, as well as of launching appropriate actions, may be hampered by the lack of supporting enforcement infrastructure. Further, next to the technical enforcement hurdles, digital contracts bring about multiple legal challenges. The status of the smart contract differs under local jurisdictions, as do the protection and redress

[48] Daugherty, Paul R., and H. James Wilson. *Human+ machine: Reimagining work in the age of AI*. Harvard Business Press, 2018; Ronald C. Arkin, Governing Lethal Behavior: Embedding Ethics in a Hybrid Deliberative/Reactive Robot Architecture, Technical Report GIT-GVU-07-11, http://www.cc.gatech.edu/ai/robot-lab/online-publications/formalizationv35.pdf; Geiss, Robin. *The international-law dimension of autonomous weapons systems*. Friedrich-Ebert-Stiftung, International Policy Analysis, 2015.

[49] Aichholzer, ibid at fn. 6.

[50] C. D. Clack, V. A. Bakshi, and L. Braine, "Smart contract templates: foundations, design landscape and research directions," 2016.

[51] J. Stark, "Making Sense of Blockchain Smart Contracts," 2016. Retrieved from https://www.coindesk.com/making-sense-smart-contracts

[52] Wallis, Kevin, et al. "Agreements between Enterprises digitized by Smart Contracts in the Domain of Industry 4.0." *arXiv preprint arXiv:2007.14181* (2020).

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opportunities when something goes wrong. Further, often the applicable law and/ or competent dispute jurisdiction are not clearly determined in the initial agreements.[53]

5.2 Skills requirements

A fundamental challenge for the rule of law is the high level of development dynamics in the technical area. Fast innovation cycles lead to a constant need for adjustment and an intrinsic enforcement deficit. New skills and approaches are needed, which would provide for the examination of the legal compatibility of a technology before and during its development, but not in a reactive, post-implementation manner.

Accordingly, next to the necessary skills in the legal disciplines referred to above, the proper tackling of the presented challenges will require an understanding of the development and control of data-driven manufacturing processes and their underlying business models, as well as know-how in areas such as IT security, automation, big data analysis, production and logistics processes.[54] Accordingly, legal professionals need to acquire skills in:

- International business standards and practices (international trade + international trade law)
- (Basic) knowledge of the ethical, legal and social implications of the KET, including
    - IT literacy skills and
    - selected disciplinary specializations, as a part of lifelong learning, as well as
    - systems knowledge.

The above skills would better position legal practitioners to design tailored legal terms to digital contracts and conditions to limit risks and establish accountability structures, as CF innovation processes evolve.This cross-fertilization of legal and technical disciplines will further provide useful insights for disciplinary specializations of floor managers and other related factory staff.

Further, there appears to be a growing consensus that the future factory floors will require considerable amounts of soft skills, such as emotional intelligence, critical thinking, innovation, communication, collaboration, leadership, and teamwork to cope in a trans-national and a transdisciplinary environment.[55] As these skills cannot be automated, it cannot be relied on intelligent machines to apply common-sense; neither can they show empathy, which humans need to do to increase productivity when working in smart factories.[56] Accordingly, any vocational training or educational institution aiming to prepare experts for

[53] Alani, Mohammed M., and Mohamed Alloghani. "Security challenges in the industry 4.0 era." *Industry 4.0 and engineering for a sustainable future*. Springer, Cham, 2019. 117-136.

[54] Aichholzer, G., Rhomberg, W., Gudowsky, N., Saurwein, F., & Weber, M. (2015b). Industrie 4.0 – Foresight & Technikfolgenabschätzung zur gesellschaftlichen Dimension der nächsten industriellen Revolution (zusammenfassender endbericht). Bericht-Nr. ITA-AIT-2, p. 41; Wienhttp://epub.oeaw.ac.at/ita/ita-projektberichte/ITA-AIT-2.pdf.

[55] Maisiri, Whisper, Hasan Darwish, and Liezl van Dyk. "An investigation of industry 4.0 skills requirements." *South African Journal of Industrial Engineering* 30.3 (2019): 90-105.
Wilson, H. James, and Paul R. Daugherty. "Collaborative intelligence: humans and AI are joining forces." *Harvard Business Review* 96.4 (2018): 114-123.

[56] Guszcza, Jim, Harvey Lewis, and Peter Evans-Greenwood. "Cognitive collaboration: Why humans and computers think better together." *Deloitte Review* 20 (2017): 8-29.

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dealing with practical and conceptual issues brought about by CF, including legal challenges, will benefit by laying an emphasis on the above.

6 Systems integration

6.1 General overview of systems integration activities in Connected Factories

This section provides an overview of activities and aspects determining the required skills and knowledge for system integration in the context of a Connected Factory. The focus of this discussion is on the management of the system integration; the position where all aspects come together.

A system integration manager oversees all ongoing activities and targeted changes involved in the connected factory. Interaction with a broad spectrum of experts, managers and stakeholders is required to cover and connect all aspects of the system, which requires a broad set of communication and management skills. Although he/she cannot be experts on all topics involved, still a good understanding of all aspects is required in order to make proper judgements. The complexity of the integration management and required skills and knowledge, depends on the several specific situations related to the system involved and it stage of development. The activities involve management of a program of R&I activities addressing both the traditional lines of expertise of the factory as well as new topics and complications still to be discovered putting high demands on learning skills and creativity.

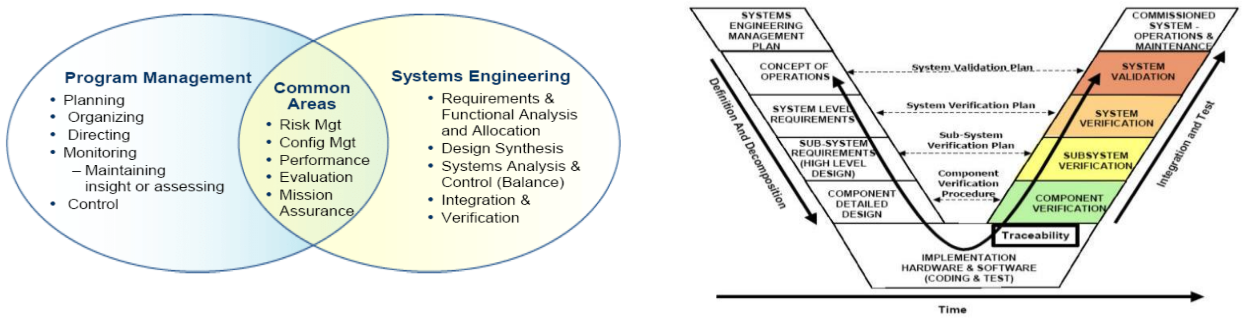

Figure 7 Examples of activities involved in the System integration process

6.2 Variations of requirements and complexity of system integration

In order to specify the required skills and knowledge, the most relevant variables influencing the function requirements and their relative importance, are discussed.

6.2.1 Digital transformation of the system

The System to be integrated is not static but evolves in a dynamic process. The activities and processes involved in System integration therefor also will gradually change. Consequently, the required skills and knowledge will depend on the stage of development of the system.

Digitalisation vs digital transformation

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- Digitalisation: automation of existing processes
- Digital transformation: Optimising the processes made possible by the digitalisation and other innovative possibilities

Level of integration of the system:

- Existing processes
- Digitalisation of existing processes
- Digital transformation of Sub-systems of the factory
- Digital transformation of the factory
- Digital transformation of the factory and direct connected entities (supply- and demand side, including logistics & transportation)
- Digital transformation of the factory and the entire supply chain

This gradual expansion of the digital transformation leads to a transition from a 'Core manufacturing skills/activities system-oriented (D4.1, section 3.3.2.) to a 'ICT expertise oriented system':

- Core manufacturing expertise' oriented system: traditional way of working of a factory
- ICT expertise' oriented system: Due to the digital transformation most human labour involves ICT skills and knowledge, where possible sector specific manufacturing skills will be gradually replaceable by data and AI along the transition; (remaining) workers will still need these skills to understand the production process and for potential interventions.
- Transition orientation system: This involves "intermediate" versions of the system during the transition towards the ICT expertise' oriented system. This stage involves different stages/levels of integration of the system.

6.2.2 Complexity of the (External) Stakeholder & Content Management

The complexity of (external) stakeholder management depends on different aspects including the societal costs and benefits involved, cooperative business models (for R&I) applied and level of integration of the system with external stakeholders/partners. Here below some examples of influential aspects are listed.

Examples of **societal impacts** (benefits and costs) influencing the complexity of stakeholder management:

- Level of Sustainable operation – lower external costs imply higher acceptability by society
- Revenues and labour creation – economic contribution to society
- Public or dedicated Infrastructure needs – level of cooperation and commitment of public authorities
- Cyber-attack risks – potential damage involved (nuclear plant vs paperclip factory)

The degree of **international operation** influences the complexity of the system integration as well:

- Language and cultural differences
- Differences in regulation, standardisation and interoperability
- National/political interests
- Larger scope of activities

Integration of ICT R&I:

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- Generic ICT solutions – standard solutions (R&I by providers)
- Dedicated development of ICT solutions – own-development (R&I by factory), dedicate solution buy-in (R&I by ICT providers and knowledge institutes) or collaborative business model with providers & developers (R&I together with ICT providers and knowledge institutes)

Integration of ICT operation with external stakeholders:

- Level of data and information exchange
- Level of harmonisation of systems
- Level of mutual dependency of processes and timing

6.3 Overview of required skills and knowledge for system integration

6.3.1 Project, Program and Portfolio management skills

The activities performed by a system integrator can be classified as project, program or portfolio management depending of the complexity of the system. As such, an important set of skills required for system integration management are in line with project, program and portfolio management skills. The required skills are specified in different acknowledged systems such as IPMA . IPMA is a competence oriented project management system, which is the reason we have selected its ICB4 (Individual Competence Baseline version 4) as basis for the specification of the required skill and discussion in this section.

As described by Vukomanoviç et al[57], with the ICB4 IPMA sets a baseline for individuals working in all three project-oriented environments, i.e. projects, programmes and portfolios (3PM). ICB4 competences are represented by the three competence areas: People, Practice and Perspective. The ICB4 is split into three competence areas: People (10 elements), Practice (14 elements) and Perspective (5 elements), which are shown in Figure 8. These competence area elements specify, what is commonly required in the project, program and portfolio management domains[58].

Figure 8 IPMA individual Competence Baseline ICB4[59]

[57] Vukomanoviç, M.; Young, M.; Huynink, S. IPMA ICB 4.0—A global standard for project, programme and portfolio management
competences. Int. J. Proj. Manag. **2016**, 34, 1703–1705.

[58] These competence area elements are further broken down into key competence indicators by domain, but for this assessment the level of the competence area elements is sufficient.

[59] Source: IPMA Individual Competence Baseline (ICB4) | Henny Portman's Blog (wordpress.com)

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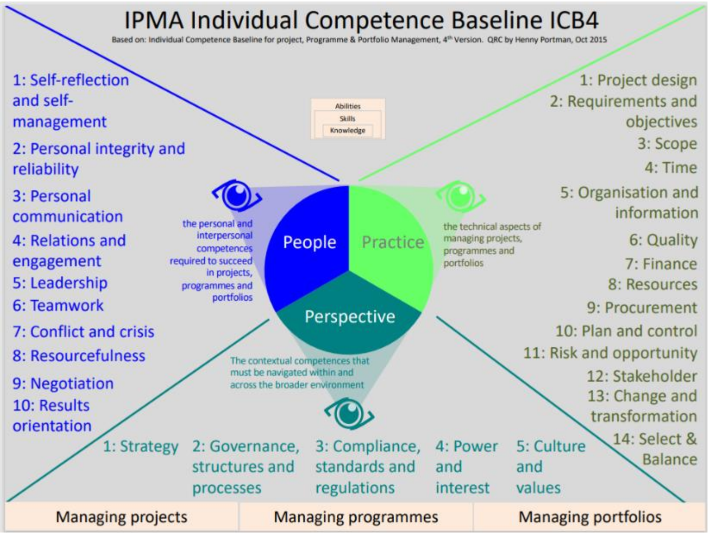

Although all listed skills are required for a system integrator, the complexity of the situation may put more demand on certain skills than in less complex situations, as explained in section 6.2 In Table 3 an overview is made of skills that may be required at a higher level for several of the situations discussed.

Table 3 Influence of specific situations on complexity of activities for which the skills are required, '+' indicates a higher skill/competence level requirement

ICB4 - competence area elements	**Situations influencing complexity and competence level required**			
	Societal impacts/risks	**International orientation**	**ICT R&I requirements**	**External cooperative system integration**
people:				
Self-reflection and self-management	+	+		+
Personal integrity and reliability	+			+
personal communication	+	+		+
relations and engagement	+			+
leadership	+			+
teamwork	+			+
conflict and crisis	+			+
resourcefulness	+		+	+
negotiation	+			+
result orientation			+	+
Practice:				
Project design			+	+
requirements and objectives			+	+
Scope			+	+
Time			+	+
Organisation and information	+		+	+

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ICB4 - competence area elements	Situations influencing complexity and competence level required			
	Societal impacts/risks	International orientation	ICT R&I requirements	External cooperative system integration
Quality			+	+
Finance			+	+
Resources			+	+
Procurement			+	+
Plan and control			+	+
Risk and opportunity	+		+	+
Stakeholder	+		+	+
Change and transformation	+		+	+
Select & Balance			+	+
Perspective:				
Strategy	+		+	+
Governance, structures and processes	+	+		+
Compliance, standards and regulations	+	+		+
Power and interest	+	+		+
Culture and values	+	+		+

In case of **higher societal impacts** of the activities of the factory and/or caused by its digital transformation many of the skills under the competence area people and perspective may be required at a higher level than under other circumstances. Result orientation (people area) and many Practice area competences require 'normal' attention in this situation, unless for the skills related to the implications of the transition and the interaction with the stakeholders.

International orientation of the activities of the factory or of aspects related to the digital transformation, puts higher demands on the skills related to the perspective competence area and language skills (personal communication). Cultural differences should be treated with care and more practically potentially there may be differences in governance/organisation, standards and regulation to be taken into account. Dealing with power and interests issues may come into play as regular inter-organisational issue but in specific international relationships this may involve national and/or political interests as well.

In case **dedicated ICT R&I activities** are required for the system integration activities this may put higher demands on the Practice Area competences. In addition, People Area competences such as resourcefulness and result orientation may be above average required. Also the ability to deal with Strategic aspects may be of higher relevance.

A higher **degree of integration of the system with external stakeholders/partners** may put higher demands on all the ICB4 skills. The stakeholder management and interaction cannot be dealt with independently from the implementation and operation of the system. When the systems of different stakeholders are or will be

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connected with each other, success and failure of actions of one stakeholder are shared with the others as well. As such all competence Area competences may be required at a high level and at the same time.

The relevance of the situations assessed in Table 3 may differ depending on the stage of the digital transformation. In Table 4 the relevance of the situations for the three stages of development is indicated, under the assumptions the situations that are relevant for the factory in consideration from start to end of the transition. Consequently, the required skill levels (Table 3) will also vary over time.

Table 4 Relevance of the situations in Table 2 by digital transformation stage

	Relevance (Not, Low, Medium, High, Top)		
	Core manufacturing expertise oriented system	**transition phase**	**ICT expertise oriented system**
Societal impacts/risks	H	T	H
International orientation	M/H	H	T
ICT R&I requirements	T	T	T
Cooperative system integration beyond the factory	H	T	T

Where **societal impacts** are of high relevance in the starting stage of development this will increase in the transition phase where changes can be expected for different stakeholders. Where some impacts may improve for society others may come instead, such as negative direct labour impacts due to automation and higher infrastructure capacity needs due to enlargement material and product flows resulting from a potentially required enlargement of the of production to justify the digital transformation (economies of the scale). Assuming the societal impacts will be solved it may be possible that this will be of lesser relevance at the end stage of transition.

Where **international orientation** is or will be relevant at some modest degree for the factory in consideration, this relevance will gradually increase to a very high level during the process. This may be caused by the global ICT R&I/technology related developments or enlargement of markets and the gradual broadening of integration of systems.

ICT R&I is of course very relevant for system integration of a connected factory. This can be assumed to be of top relevance from start to end of the transition process.

System integration will at first focus on the processes within the factory and integration **with external stakeholders and partners** will start at a lower level of intensity until the all internal process of the factory itself are integrated. During the transition this will integration of systems and interdependence of stakeholders/parts will gradually grow until full connectivity is reached.

6.3.2 Relevant knowledge areas

In addition to the project, program and portfolio management competences, discussed in the previous section, knowledge on relevant topics for the connected factory in consideration and the digital transformation are of high relevance for the system integrator. In Table 5 a set of key knowledge areas has been listed. This list contains knowledge areas which are cross-sectoral or sector specific for activities performed in factories, in particular manufacturing, supply chain management and sustainability. Further several more specific ICT knowledge areas are included derived from CF2 D4.1 - 'Identification of emerging skills and job requirements' as well as from previous sections.

Table 5 Relevance of knowledge areas by digital transformation stage

	Relevance (Not, Low, Medium, High, Top)		
Knowledge area	**Core manufacturing expertise oriented system**	**transition phase**	**ICT expertise oriented system**
Manufacturing - sector specific	T	T/H	H
Manufacturing - cross sectoral	T	T/H	H
Supply Chain management - sector specific	T	T/H	H
Supply Chain management - cross sectoral	T	T/H	H
Sustainability - sector specific	H/T	T	H
Sustainability - cross sector	H	T	H
ICT - sector specific applications	T	T	T
ICT - cross-sector applications	T	T	T
ICT - Cyber-security	H	T	T
ICT - Privacy	H	T	T
ICT - Data processing/analytics	H	T	T
ICT - Data/information exchange	H	T	T
ICT - AI	M/H	T	T
ICT/engineering - Robotics (including sensors, photonics, etc)	H	T	T
ICT - system design	H	T	H/T
Interoperability and standards	H	T	H/T
Business models	H/T	T	H/T
Standardisation and interoperability	T	T	H/T
Legal aspects	T	T	H
Recycling/waste management	H	T	H
Resource efficiency	M/H	T	H
Circular design/economy	N	T	H

Table 5 indicates the relevance of each of the knowledge areas in the different stages of the digital transformation. An essential aspect of the **digital transformation** is the gradual digitalisation of knowledge and the automation of the application of the knowledge and operational skills by AI and robots. This development can be expected to lead to an increased dependence on knowledge of the automated system rather of the individual humans that operate and manage it. At the same time the ICT related knowledge will become more important and/or will remain of top relevance also at the later stages of the digital transformation.

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The **traditional knowledge requirements** related to the factory will gradually be reduced, however may remain of high relevance for the system integrator to be able to oversee the system and the consequences of potential changes.

The **knowledge areas** related to the **cross-cutting issues** will be of top relevance during the digital transformation also if they were of lower relevance at the starting point. As for the traditional knowledge areas of factories the automation will reduce the need for this knowledge at a later stage of the transformation.

6.4 Conclusions system integrator

Specific situations of a factory determine the required skills of the system integrator. In particular integration of the system with external stakeholders/partners in the supply chain which gets increasingly relevant during the process of digital transformation, puts high demands on the full spectrum of the required project/program/portfolio management skills. Other situations (societal impacts, international orientation) may vary in relevance along the transition high demand of sub-sets of these skills. Dedicated ICT R&I is of top relevance along the entire transition pathway; for factories where this has high relevance, the required sub-sets of skills (see table 2) could be regarded as minimal requirement for the system integrator at all stages.

The required ICT knowledge for the digital transformation is of top relevance once the transition is initiated and therefor may also be regarded as minimal requirement for the system integrator. Where possible knowledge will be gradually integrated in the system and the use of it is automated by AI and robots. Knowledge on the topics remains highly relevant for the system integrator as long as human interventions are required. During the system development phase in which the knowledge is integrated in the system these knowledge areas obviously will (temporarily) be of top relevance. This may imply that different persons should fulfil this role at different stages of the transition or the system integrator should lean more on managerial skills and cooperate with/delegate responsibilities to specialists on these sub-systems for which the knowledge is required.

7 Conclusions

This study aimed to explore and offer a reflexion on the new skills requirements demanded by a number of cross-cutting factors affecting the deployment of connected factories. The number of new skills requirements identified track back and must build up upon the basic knowledge on the general and specific purposes enabling connected factories (robotics, AI, HPC, cloud computing, augmented reality, etc). In turn, the number of new skills requirements taken in isolation within each of the cross factors considered amount to a large number. A preliminary cross analysis of the listed skills requirements identified indicates that there are great deal of complementarities and overlaps between the skills requirements identified. This is due to the close co-evolution of the cross-cutting factors considered in the analysis. This means that it would be possible to reach an agreement on a limited number of key critical skills requirements. This would with the appropriate agreement on the terminology used in the different epistemological fields of expertise that addressed each of the cross factors analysed. Such agreement could be one of the next steps to be conducted in the next task of work package 4 (task 4.3).

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