BIG DATA CHALLENGES IN SMART MANUFACTURING

A Discussion Paper on Big Data challenges for BDVA and EFFRA Research & Innovation roadmaps alignment

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Executive Summary

The present discussion paper aims at identifying major research and innovation challenges for data-oriented Factories of the Future in 2025. It originates from a cross-domain collaboration between the Smart Manufacturing Industry subgroup of the BDVA cPPP (Big Data Value Association contractual Public Private Partnership http://www.bdva.eu/) and the Connected Factories cluster of the FOF cPPP (European Factories of the Future Research Association http://www.effra.eu/).

The BDVA background is materialised by its SRIA (Strategic Research and Innovation Agenda) five Technical Challenges, which address common requirements collected from several different application and industrial domains (e.g. manufacturing, energy, healthcare, transport, media, telco) when aiming to integrate different and diverse data sources (such as structured data, Time Series from the Internet of Things, Geo-spatial data, multimedia and video data, textual and social networks data, artificial intelligence and semantic semi-structured data) for value added business and social applications, such as planning, optimisation, intelligence and decision support.

The FOF background is materialised by its validation business scenarios of Smart Factory, Smart Product and Smart Supply Chains as projected to 2025 by the Connected Factories personas of Autonomous, Product-Service and Hyper-connected factories of the future. FOF is also providing its reference architectures, originated e.g. from RAMI 4.0 Plattform Industrie 4.0 and the Industrial Internet Consortium, and data-driven implementation guidelines such as the layered data-buses architecture of IIRA 1.8.

In the last 15 months and starting from the BDVA Valencia Summit in November 2016, experts of both communities have jointly conducted a deep analysis of FOF scenarios and architectures through several remote and physical meetings, with the aim to identify and specify new technical challenges for a full adoption of BD technologies and data-driven business models in the Manufacturing Industry. In this first period, a total of 56 research and innovation challenges (inspired by the five BDVA SRIA topics of data management, processing, analytics, security and visualising) for the BDVA+FOF joint communities have been specified and classified in the three Grand Scenarios of Smart Factory, Smart Product and Smart Supply Chain scenarios.

As a first result, we can say that in the Smart Factory scenarios, new highly distributed data processing architectures, such as edge or fog computing ones, are envisaged to complement the current Real-Digital world dichotomy between embedded real-world systems and remote cloud-HPC systems. In the Smart Product scenarios, a data-driven approach based on advanced analytics and artificial intelligence allows the closed loop interaction among all the phases of the product lifecycle, supporting for instance product-service design and engineering (professional knowledge and wisdom of the crowd), product constant tracking and tracing (as-designed, as-built, as-maintained data) and environmental sustainability at the End of Life (de- re- manufacturing, circular economy). In the Smart Supply Chain scenarios, the most important challenge regards data security and confidentiality in hyper-connected global but agile value networks, where collaboration and partnership are mandatory, but needs to be ruled in
legal, technological and business terms. The Data Sovereignty concept has recently emerged as a very promising principle, under which to build next generation industrial data platforms at European and trans-national level.

In the following 15 months, the activity of the SMI subgroup will be reinforced by new projects which recently have been funded in both BDVA and FOF calls and more attention will be given to non-technical topics and migration pathways, regarding especially legal-regulatory aspects, roles-skills-competencies, innovative business models and support to SMEs through specific Big Data Innovation Hubs to be built as a smart specialisation of the regional DIH of the Digitising EU Industry communication.
# Executive Summary

Big Data challenges in Smart Manufacturing

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Editorial Team and Contributors

Contributions from Valencia Summit (Nov 29th 2016)
1. INTRODUCTION

1.1. Background and Motivation

In fact, Manufacturing Industry, explicitly indicated in the BDVA SRIA vertical markets picture, is one of the most promising sectors for Data-driven solutions and Data-oriented new Business models. During the Data Economy Conference organised in Budapest\(^1\), IDC presented their perspective about present and future Data Market in Europe\(^2\). The current estimation for the EU28 in 2017 is around 65 B€ (which is 10.4% of the whole ICT market) with a growth perspective for 2025 spanning from 96 to 146 B€, depending on which growth scenario will materialize. In the same analysis, IDC put Manufacturing at the first place in 2017 (14 B€) and in the 2025 projections (23 B€), revealing a leading role played by this sector in the overall Data Economy, especially through the following three main scenarios: improving production processes and operations; supporting service and product innovation; analysing machine or device data. The Digitizing European Industry (DEI) communication of April 19th 2016 indeed identified three main domains where Industry 4.0 technologies (and Big Data among them) could impact Manufacturing Industry: Products (digital inside), Processes (production) and Business Models (servitisation).

H2020 Research and Innovation Actions concerned with “Digitising European Manufacturing Industry” are in charge of another contractual PPP named Factories of the Future (FoF), Similarly to BDVA, the European Factories of the Future Research Association (EFFRA) represents the private part of the PPP and expresses the research and innovation needs and requirements of the EU Manufacturing Industry.

EFFRA 2020 roadmap identifies 6 main domains of intervention (Advanced manufacturing processes; Adaptive and smart manufacturing systems; Digital, virtual and resource efficient factories; Collaborative and mobile enterprises; Customer focused manufacturing; Human centred manufacturing) and some priorities for 2018-2020 FoF PPP work-programme (including agile value networks; excellence in manufacturing; human factors; sustainable value networks; interoperable digital manufacturing platforms). With the aim to find an agreed synthesis, the SMI subgroup firstly adopted the “Smart Manufacturing Industry” concept definition, including the whole value chain gravitating around goods production, secondly identified three main Grand

\(^1\)http://ivsz.hu/data-economy-conference
\(^2\) Capturing Value: how the power of data will drive the economy, Data Economy Conference, January 2018, http://ivsz.hu/data-economy-conference/presentations/
Scenarios aiming at representing all the different features of a SMI in Europe:

1. **Smart Factory** grand scenario, where data is generated inside production lines and analytics is needed for safety, optimization and diagnosis of the plant as well as of the blue collar workers. Key topics in this scenario are: Factory Automation; Machinery & Robots; Internal Logistics; Smart Workplaces; Cyber Physical Production Systems (as in the original German Industrie 4.0 concept). In this domain, Industrial Analytics could support advanced applications including but not limited to e.g. Production Lines design and ramp-up; Production Monitoring and Control; Production Planning and Scheduling; CPS modelling and simulation; Energy/Waste Consumption Optimization; Diagnosis and Predictive Maintenance; Zero Defect Manufacturing; Workplace Human-Machine interaction; Workers Training and Augmented Reality.

2. **Smart Supply Chain** grand scenario, where data is generated by ecosystems of suppliers, providers, distributors, retailers and analytics is needed for value chain integration and white collar workers collaboration. Key topics in this scenario are: Trends and Sentiment analysis; Open Innovation and Living Labs; Supply and Distribution Chain Optimisation; Inbound and Outbound Logistics optimization; Closed loop Manufacturing synchronization; Industrial Symbiosis; Co-operative Working Environments for engineers and managers; Retail and Consumer experience monitoring; product-service cross-domain ecosystems.

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

More recently, a cluster of 10 FoF projects in the domain of digital platforms for manufacturing has been created and ‘ConnectedFactories’ is a coordination action from the same FoF-11-2016 call, that aims at developing scenarios for the deployment of digital platforms for manufacturing within the wider context of digitisation of manufacturing.

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

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

A fourth cross-cutting persona has been identified as a Small-Scale Digital Factory implementation of one of the three personas above, with the mission-focused on digitalisation for SME-driven sustainable manufacturing. Low-cost, light, easy to use and adopt data-driven solutions are the essence of this fourth persona. Through a series of consensus building workshops, ConnectedFactories has defined firstly the main characteristics of such four 2025 personas and is now developing the
pathways towards the realisation of the vision described for each of the personas, while considering different key aspects such as Platform characteristics, Data, Skills, Security, Regulation, business models, etc., as depicted here in Figure 1.

Manufacturing is considered as an important factor for the European economy and the societal development and growth. The socio-economic and financial numbers, as well as the predictions towards 2020, highlight the need for further IT support in this sector. This is for example well presented in the EFFRA policy report for the Factories of the Future³, which develops around the key research and innovation priorities as the roadmap for the manufacturing 2025 vision. As stated there, ICT aspires innovation in the manufacturing intelligence through enabling the management of huge volumes of data being collected from collaborative supply networks and connected devices and optimising the production planning and scheduling. In spite of the enormous potential of the ICT-for-Industry business cases, the actual adoption of ICT and Big Data technologies in particular regarding Manufacturing SMEs, remains quite limited and unsatisfactory. This lack of adoption of this data-driven paradigm is being limited by the adoption in the SMEs of huge and complex architectures for data analytics. Nevertheless, the promotion of hybrid big data architectures could bring the SMEs with flexible, interoperable and scalable analytics that satisfy their business needs at lower costs.

³ [http://www.effra.eu/attachments/article/129/Factories%20of%20the%20Future%20Roadmap.pdf](http://www.effra.eu/attachments/article/129/Factories%20of%20the%20Future%20Roadmap.pdf)
According to a recent market study⁴, commissioned by Atos to Forrester Consulting, manufacturing companies are using, or considering using, data analytics mainly to do predictive maintenance of manufacturing equipment (77%), to optimize supply chains (79%) or to optimize product logistics and local assortment (79%). The complete results are reported in Figure X: Manufacturing Data And Analytics Use Cases. This confirms our choice for the three grand scenarios to be elaborated in this paper.

Moreover, IDC’s European Vertical Markets survey conducted at the end of 2017 found that approximately 32% of interviewed manufacturers already used Big Data and Analytics solutions, with another 7% planning to introduce them within the following year. Big Data initiatives are gradually moving beyond the IT department and reaching business intelligence/analysts across lines of business. The demand is especially driven by the analysis of operational data and factory automation. A key driver of Big Data Technology adoption is the capacity to bring in new revenue from information-based products and services, while embedded intelligence will drive the highest profitability levels. IDC sees a majority of large manufacturers engaged in integrating information from myriad sources with predictive and prescriptive analytics, machine learning, and cognitive computing to drive continuous improvement in how data value is developed and realized throughout the value chain. Monetization of data from and about products, customers, and markets is becoming embedded into the enterprise’s business strategy and is about to become a significant source of revenue and competitive strength. The sectors that are currently benefitting more from this trend are automotive and industrial machinery. Many market leaders in these sectors are based in Western Europe, so the region is in a particularly good position to profit from this trend⁵.

Figure 2 Data Analytics Use Cases in Manufacturing

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⁴http://go.atos.net/LP=573
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Smart manufacturing requires being integrated horizontally across the value chain, from product development to service. Manufacturers in many sectors are investing in simulation and analytics powered development, geared around the notion of digital twins, in which products, processes, and services are conjointly designed and simulated to reduce time to market and better align them with demand expectations.

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

IoT is going to be a major driver for Big Data and analytics — and especially cognitive/AI — spending in Western Europe in the coming years. IDC predicts that IoT will double the amount of data businesses generate, and advanced intelligent analytics will be essential to effectively analyze and act on that data. With IoT analytics, organizations can potentially leverage real-time information to improve decision making, optimize production in manufacturing, enhance customer service levels, and reduce costs — for example, through predictive maintenance, lessening the impact of unplanned downtime. According to the most recent IDC IoT Survey, approximately 40% of enterprises are already using analytics in their IoT use cases.

Figure 3 Use of Big Data and Analytics by Country (% of enterprise respondents)⁶

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Big Data challenges in Smart Manufacturing

For instance, a recent survey conducted in Italy among more than 300 Manufacturing Industries shows an insufficient awareness of the Industry 4.0 technologies (38% affirm they do not know even what it is; 31% they’ve just read articles and papers) and a poor set of early adopters (average 15% of the interviewed companies). Industrial Analytics was one of the key enabling technologies considered for the survey and showed an adoption percentage variable from 11% to 20% in the three grand scenarios. The 2017 situation in Italy (Figure 4 Observatory Industry 4.0 2016-2017 in Italy) shows a significant improvement of the adoption of all the Industry 4.0 technologies. This is specifically due to the launch of the Piano Nazionale Industria 4.0 at the end of 2016 to support not just purchases of equipment and machines (fiscal incentives), but mostly awareness creation and development of skills and competencies through SME-oriented Digital Innovation Hubs.

Similar studies conducted in other EU Countries and considering that Italy Manufacturing/GDP ratio is quite aligned with the EU28 average of 15%, suggest us the assumption that EU28 Europe is not so far away from Italian figures. In fact, Industrial Analytics IoT report shows7 that many German and EU companies (69% of survey respondents) see Industrial Analytics playing a crucial role in their organizations in 5 years, although only few of them (15%) are applying it now.

Figure 4 Observatory Industry 4.0 2016-2017 in Italy (Source: Politecnico di Milano)

7 https://digital-analytics-association.de/dokumente/Industrial%20Analytics%20Report%202016%202017%20%20vp-singlepage.pdf
Finally, in the domain of Supply Chain management, a comparative analysis of the SCM solution vendors shows up the top 20 supply chain software suppliers, based on revenues. According to this analysis, supply chain execution and planning software grow faster than other areas, reaching a total of almost 11% gain each. The top software solution providers are listed in this report, showing up that, although Gartner predicts an evolving growth of 9.5% for the Compound Annual Growth Rate (CAGR) in next five years, the expected revenues of $16.283 billion in 2020 might be captured by the market leaders.

However, the integration of multimodal and multisource data from various systems involved in the manufacturing operations chain will significantly impact the SCM software in the coming years. This is reflected in the Global Manufacturing Outlook 2016 published by KPMG, in which the exploitation of Internet of Things technologies and analytics are arisen as key areas of investment for the respective sectors. These technological priorities will advance the competitive advantage of the manufacturing organisations, towards enhancing the productivity of the factory plant and effectively address the environmental changes, such as customer orders. This will enable a clear motivation for data-driven factories of the future, through the technological transformation of the manufacturing processes, starting from key area of focus.

The next generation of integrated solutions and platforms for smart manufacturing will employ ICT technologies that impact the way that big data coming from the factory plant and the physical world are stored, mined and analysed to harvest advanced reasoning of the data value in the manufacturing processes and comprehensive monitoring and visualisation. Such data can be integrated in the context of cloud-based open services platforms that will facilitate modelling, combination of data analytics with semantics for exploring and reinforcing the acquired knowledge, multi level simulation and analytics for improving production quality and throughput. On top of that, factories of the future envision the deployment of complex event processing techniques that enhance machine and production state detection and analytics across the supply networks and the production lines. Through cloud-based data collection and analysis, the next generation of manufacturing processes will be enhanced with integrated and cloud-based cross-domain decision making platforms that aggregate information from different domains (using IoT technology), combine and fuse the information (semantics) and monitor IoT devices with modelling, simulation and adaptive optimization techniques. Another relevant aspect regarding open cross-domain decision-making platform is the promotion of rapid development of application using the same data analytics and processing architecture available in the cloud.

According to an IDC survey on the future for cloud-based supply chain management (SCM) solutions, conducted on behalf of Oracle, the perceived strategic advantages from the deployment of SCM software lie mainly in the implementation of solutions for big data management, processing, analytics and visualization. They will unlock the potentials for more customer centric processes, the optimisation of the end-to-end supply chain processes, the increase in operational efficiency, the improvement in productivity and the achievement of strategic change goals in smart manufacturing.

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such as performance optimisation and cost savings. The market needs will result in an increased demand for big data SCM solutions, with the product lifecycle management and the logistics-global trade to experience the most growth. However, the undoubtable advantages that big data brings into smart manufacturing and productisation, such as faster implementation and improved customer service, will raise concerns regarding data security and protection of the data value in a manufacturing environment, as well as regarding the disruption both on the IT infrastructure and the business operations levels. Creating awareness on the Big Data enabling technologies and increasing the number of early adopters in the Manufacturing Industry are the two main aims of this subgroup.

### 1.3 Mission and aims of this Discussion Paper

The BDVA Task Force 7 (TF7 also called Application) is the Task Force where Big Data Technologies (or more in general Information and Communication Technologies ICT) meet scenarios, use cases and requirements from different Sectors and Application Domains (including Operational Technologies OT). Whenever IT meets OT, a marketplace able to meet demand and offer can be identified, designed and also depicted as a coin metaphor with its two independent but connected sides.

In the case of the **Smart Manufacturing Industry** subgroup, we need to design and implement the metal of the coin, which is able to harmonize the two sides, characterized by different technical and non-technical priorities, different degrees of maturity and diverse digital innovation models.

In a more tactical scenario, if we put on the IT Big Data side of the coin the SRIA Technical and non-Technical Priorities and on the Manufacturing side of the same coin the Industry 4.0 paradigm and its operational scenarios, we could try to identify some challenges and **symbiotic collaboration processes** embedded in the metal of the coin able to facilitate the adoption of technology on the one side, and to support the migration of users’ assets and competencies towards the new technologies on the other side. These processes in the end will form the metal of the coin and be able to define TRL increase / early adoption / large-scale experimentation / best practices paths from IT to Manufacturing and Product-Services / Processes / Skills / Business Models migration paths from Manufacturing to IT.

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

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13 SRIA version 3.0 at the time of writing this document
2 REFERENCE MODELS AND ARCHITECTURES ALIGNMENT

2.1 The BDVA SRIA 4.0 Reference Model and Technical Priorities

The Strategic Research and Innovation Agenda (SRIA) defines the overall goals, main technical and non-technical priorities, and a research and innovation roadmap for the European Public Private Partnership (PPP) on Big Data Value. In the context of this paper the most important information is related to the Reference Model, for the overall positioning of concepts and the technical priorities, for the relation with manufacturing scenarios. The BDVA Big Data Value Reference Model is reported in the figure 5 below.

Figure 5: Big Data Reference Model

Big Data Types & semantics

Structured
Data/ Business intelligence
Time series, IoT
Geo Spatial Temporal
Media
Image Audio
Text, Language, Genomics
Web
Graph
Standards

Big Data Priority Tech Areas

Data Visualisation and User Interaction
1D, 2D, 3D, 4D, VR/AR

Data Analytics
Descriptive, Diagnostic, Predictive, Prescriptive, Machine Learning and AI, Deep Learning, Statistics

Data Processing Architectures and Workflows
Batch, Interactive, Streaming, Near-time, Data

Data Protection
Anonymisation

Data Management
Collection, Preparation, Curating, Linking, Querying, Storing, Data Reasoning, Data Variant
DB types: SQL, NoSQL (Document, Key-Value, Column, Graph)

Cloud and High Performance Computing (HPC)
Things/Assets, Sensors and Actuators (Edge, Fog, IoT, CPS)

The BDV Reference Model has been developed by the BDVA taking into account the whole Big Data Value chain. The BDV Reference Model may serve as common reference framework to locate Big Data technologies on the overall IT stack. It addresses the main concerns and aspects relevant to Big Data Value systems.

Those technical priorities that are relevant for the paper as expressed in the BDV Reference Model are elaborated in the remainder of this section:

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

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

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

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

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

Following the evolution of the SRIA priorities, also this paper will be updated to capture relevant aspects to be taken into consideration in the Smart Manufacturing domain.
2.2 Plattform Industrie 4.0 and Industrial Internet Consortium Reference Architectures Alignment and Interoperability

Industrial Internet Consortium and the German Plattform Industrie 4.0 have recently developed reference architectures for the Industrial Internet: The Industrial Internet Reference Architecture (IIRA)\(^1\), and the Reference Architecture Model for Industrie 4.0 (RAMI 4.0)\(^2\), respectively. Making manufacturing operations intelligent by digitally orchestrating and optimizing its processes is the common goal of both architectures.

RAMI 4.0 includes many aspects of manufacturing value chains with the full product lifecycles from the first idea to end-of-life. IIRA emphasizes broad applicability and interoperability of its IIoT technical frameworks - with its reference architecture - across industries. The on-going efforts to ensure interoperability of both architectures have been recently documented in the paper “Architecture Alignment and Interoperability, An Industrial Internet Consortium and Plattform Industrie 4.0 Joint Whitepaper”\(^3\), focusing on mapping the IIRA Functional Domains/Crosscutting Functions and RAMI 4.0 architecture Layers.

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\(^1\)http://www.iiconsortium.org/IIRA.htm
\(^2\)https://www.vdi.de/fileadmin/vdi_de/redakteur_dateien/gma_dateien/5305_Publikation_GMA_Status_Report_ZVEI_Reference_Architecture_Model.pdf
\(^3\)http://www.iiconsortium.org/pdf/JTG2_Whitepaper_final_20171205.pdf
IIRA is an IIoT reference architecture that is business-value-driven and concern-resolution-oriented. It has two main relevant Functional Domains for BD:

- **Information domain** with functions for collecting, transforming and analyzing data to acquire high-level intelligence of the entire system.
- **Business domain** with functions integrating information across business systems and applications to achieve business objectives, such as work planning, customer relationship management (CRM), enterprise resource planning (ERP), manufacturing execution system (MES).

IIRA also identifies a set of crosscutting functions that include connectivity, distributed data management and integration and industrial analytics. IIRA emphasizes industrial analytics in its architecture, focusing on the closed-loop process of collecting, analyzing machine data and applying the analytic insights to the decision-making in the operational and manufacturing processes.

RAMI 4.0 is a Service-Oriented Architecture (SOA) framework that combines services and data. It has horizontal integration by focusing on value networks and vertical Integration within a factory. The architecture is defined through 3 dimensions: (1) six layers in terms of properties and system structures with their functions and function-specific data, (2) life cycle and value stream from idea, development, production and maintenance of different asset type and (3) hierarchy levels that describes the functional hierarchy of a factory.

To summarize, Industrie 4.0 (RAMI 4.0) includes many aspects of manufacturing value chains with the full product lifecycles from the first idea to end-of-life, whereas IIC (IIRA) emphasizes applicability and interoperability of its IIoT technical frameworks (with its reference architecture) across industries.

Regarding BD, two specific RAMI 4.0 layers are mostly of interest. Firstly, Information layer that describes services and data offered, used, generated or modified by the technical functionality of the asset (machines, personnel, product, raw material and software) and secondly, Communication layer that provides a channel for service and event/data to the information layer, and services and control commands to the so called Integration layer.

Regarding the implementation approaches to inspire Smart Manufacturing Industry research challenges, both architectures of RAMI4.0 and IIRA provide different views for each of the three scenarios:

**Smart Factory scenario**: RAMI 4.0 has a strong focus on manufacturing, to optimize the complete manufacturing operations to deliver, operate and maintain industrial assets. Assets for RAMI 4.0 has a wide definition: machines, personnel, product, raw material and software. IIRA focuses on assets as physical things being monitored and controlled.
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Smart Product Lifecycle scenario: RAMI 4.0 focuses on products built in a manufacturing environment and they move through the product life cycle, from material to parts to components and finally to be installed on a location as assets outside manufacturing. Once they are installed and commissioned into operation, they may be operated and maintained under an IIoT system based on IIRA. Therefore, industrial products (where RAMI 4.0 applies) appear in multiple industries (where IIRA applies) so they must interoperate.

Smart Supply Chain scenario: IIRA addresses issues about IIoT across industries and stressing shared features and interoperability across industries.

2.3 A Data-driven Mapping of BDVA Reference Model to Manufacturing Industry scenarios

The IIRA 1.8 includes a data-driven viewpoint to its reference architecture based on the concept of layered data-buses, which is quite aligned with the BDVA SRIA. Data Interoperability (exchange and sharing) is in fact guaranteed by different layers of data-buses through a Data Security infrastructure (often called Data Sovereignty), while within each layer we need end-to-end Data Management (lifecycle from collection to end-of-life), Data (in Motion) Processing, Data Spaces and Architectures, Data (at Rest) Analytics and Data Visualisation. It is worth saying that data-buses could be secure highways for both Data in Motion (streams) and Data at Rest interoperability across different administrative domains.

At Machine layer, the SRIA data challenges mostly apply to smart systems, embedded in both products and production lines, for instance in ECSEL Industry4.E (centred on the ECSEL project Productive4.0) Lighthouse initiative18; at Unit layer, an edge/fog highly distributed architecture could include data (in Motion) management-processing SRIA functions, for instance in the Digital Shopfloor Alliance among several Smart Production projects in Connected Factories cluster19; at Site layer, semantic interoperability of data is necessary to dominate the heterogeneity of sources, protocols and formats, for instance like in the Big Data Europe project20, now converged to the new BOOST 4.0 BDVA Lighthouse21; at Inter-Site layer, data confidentiality and sovereignty assume particular relevance in order to feed data economy new business models, for instance in the domain of DEI Industrial Data Platform, we can identify the Industrial Data Space association22.

18https://www.ecsel.eu/lighthouse-initiatives
19http://www.effra.eu/project-cluster
20https://www.big-data-europe.eu/
21http://boost40.eu/
22http://www.industrialdataspace.org/
On the basis of the above alignment and mapping to IIRA (and RAMI), the three Grand Scenarios identified in the SMI subgroup could have a data-driven implementation and could therefore identify research challenges related to the five BDVA SRIA technical challenges (chapter 3).

The **Smart Factory** and **Smart Product** (lifecycle) scenarios span from the Machine (Real World) layer to the Site layer with a Lambda-style integration between Data in Motion and Data at Rest processing-analytics. Smart Factory originates from Industrial IoT applied to Production Systems (Machines, Robots, Shopfloor Automation systems but also Workspaces and Blue-Collar Workers); while Smart Product originates from its lifecycle (usually after sales but not exclusively) and has interesting implications with new business models inspired by Service and Circular Economy. The **Smart Supply Chain** scenario superimposes an Inter-site data-bus and it is characterised by Smart Data Sovereignty contracts among the involved relevant stakeholders. It is implemented both on top of Smart Factory and Smart Product scenarios and is able to implement massive or near real time data exchanges.
Figure 8: Smart Factory and Smart Product scenarios in IIRA layered Data-buses architectures

Figure 9: Smart Supply Chain scenario in IIRA layered Data-buses architectures (Industrial Data Space)
2.4 The SMI Discussion Paper
Reference Framework

At a more technical level, the SMI subgroup started from an initial interpretation of the 5 SRIA technical priorities seen with the lenses of the Manufacturing Industry business process, as illustrated in the pictures below, which inspired our first consensus meeting during the November 2016 BDVA Valencia Summit.

Figure 10: SRIA Technical Priorities

As a first step towards raising more awareness and triggering more experimentation of Big Data technologies in Manufacturing Industry grand scenarios, the SMI group organised an interactive consensus building session during the Valencia Summit November 2016. The working reference framework was a matrix crossing SRIA Technical priorities and Manufacturing Industry grand scenarios, while the task for each of the three rotating working groups was to identify and prioritise challenges inside this reference matrix.

The Reference Framework and the pictures of the posters used to run the session are reported in the following picture. The main outcomes of the interactive session were collected and reported in tables where one bullet point corresponds to one post-it. These tables details are reported in the annex for completeness.
After that consensus-building meeting, our community started working on this discussion paper by remote conferences and physical events, mostly organised in coincidence with the BDVA AG events. The next Chapter 3 shows the results of such activities, as research and innovation challenges per Manufacturing Industry scenario.
2. Implementation Strategy
3. SMART MANUFACTURING INDUSTRY CHALLENGES

3.1 Smart Factory Scenario

On the basis of the Valencia Summit meeting and of subsequent investigations, we could identify the following set of challenges for the Smart Factory business scenario.

c1. Data Management & Lifecycle Challenges. In the Smart Factory business scenario, the SRIA Priority 1 ‘Data Management and Lifecycle’ needs to be extended, so that factory modules are represented as physical and virtual objects analysed semantically, which produce, consume or process data. The challenge for data integration and business processes incorporates the standardisation of data patterns coming from CPS, sensors and ICT manufacturing systems (WMS, MES, MRP, etc.). The challenge is to effectively manage such data and identify their role in i) the horizontal integration of data values across manufacturing processes, ii) their vertical integration among the different data components within specific manufacturing processes, and iii) the cross-boundary integration covering the data semantics to be followed along the full smart product lifecycle.

a. SF1. CPS Data Sources Integration. The wide variety of deployed Cyber Physical Systems (CPS) in a smart factory causes the availability of huge amounts of data. However, since these data come from heterogeneous sources (PLCs, SCADA, ERP), their combination and integration has become a complex endeavour.

b. SF2. Automation Systems Semantic Interoperability. Trend towards solving this problem is to leverage of Semantic Web Technologies (SWT) like ontologies, linked data and reasoning, due to the arduous task of data integration and communication standardization, when it comes to include several Industrial information systems, as in the case of Enterprise-control systems (IEC62264): production scheduling, control and maintenance management. Semantic interoperability will enable the systems to understand the collected, generated and existent information. Thus, this paradigm will promote a collaborative and information sharing environment.

c. SF3. Smart Factory Data annotation. However, it remains unsolved the decision whether collected data should be annotated on-the-fly (e.g. using RDFa), or stored in its natural format in data lakes and apply Extract Load Transport (ETL) processes later on. The annotation process, refers to provide context to the data by means of labelling. For example, the information provided by a temperature sensor (lowest level in the automation pyramid) needs to be associated with the specific product variety (e.g. information coming from ERP).
that it’s being manufactured
d. **SF4 Smart Factory unstructured, semi-structured and missing Data.** Factories are also a source of non-structured data like maintenance reports or on-the-fly updated production schedules. Sometimes, sensors or communication channels may fail during a certain amount of time. The challenge is to replicate the inherent ability of operators to work easily with such kind of unstructured and missing information, and it’s also an opportunity to better pre-process such kind of data.
e. **SF5. Industrial IOT Data Availability.** The ability to integrate in the existing IT factory infrastructure of new hardware capabilities of embedded sensors that provide data ranging from instantaneous measurements (useful at machine level) to advanced analysis like statistics and predictions (of for instance values and potentially faults, involving sets of machines). The industry 4.0 paradigm, technologies like IoT and open interfaces (and APIs) mean a non-traditional way of data sources vertical integration (from process level 0 to Planning and logistics level 4 - IEC 62264).

c2. **Data Processing Architectures Challenges**

a. **SF6. On-premise vs Cloud Smart Factory Architectures.** In order to ensure data processing in real-time and in a reliable way, architectures have to be scalable and elastic. However, it is still an open issue whether these data pre-processing tasks should be done on-premises or in the cloud. Cloud federation opens the door to more flexibility to re-use cloud resources from multiple providers. On the other hand, cloud architecture is an opportunity for SMEs (specially the small ones) which can rely on cloud services for storing and processing their data without needing to have in-house IT experts.
b. **SF7. Hybrid Clouds and Edge Automation Architectures.** Some organizations, especially the ones dealing with sensitive data, are reticent to put it on the cloud. In these cases, it is very difficult to know exactly where data is, so that until technology overcomes this hurdle, they prefer the on-premises solutions and edge nodes to process data close to manufacturing point. Nevertheless, some experts advocate a hybrid cloud where both models coexist. This hybrid model can be a valuable approach to architecture, considering that it enables the combination of resources between local infrastructure with infrastructure that is scalable and provisioned on demand.
c. **SF8. Smart Factory Data in Motion, Data at Rest Integration.** Need for integration of advanced processing capabilities (including compression and streaming) of new embedded hardware that generates data-in-motion (at machine or sensor level) together with data-at-rest coming from upper manufacturing levels (cells, production lines, sites).

c3. **Data Analytics Challenges.** The Big Data Value SRIA Technical Priority 3 “Data Analytics and Models Simulation” needs to be enhanced in two ways. First, the challenge is to provide advanced mechanisms for the multi-perspective semantic representation of the relations across different datasets in the smart manufacturing, which improves the capability of the smart factory to develop predictive and prescriptive analytics, embracing advanced modelling, simulation and optimization data services. The composition of data driven events from heterogeneous smart factory objects and ICT systems will challenge the development of smart data intelligence and the compilation of different real-time response scenarios for a smart factory, including human-based assessments and CPS automated reconfigurations.
a. **SF9. Prescriptive Analytics in Industrial Plants.** Although Predictive analytics like the one used in Maintenance has not reached its maturity in the vast majority
of organizations yet, the next evolutionary step in analytics will bring towards Prescriptive analytics. It will provide, in addition of the estimations (e.g. time of failure in maintenance), the expected influence of manufacturing parameters in this estimation.

b. **SF10. Machine and Deep Learning in Smart Factory.** Lately deep learning has become one of the primary drivers and approaches to AI in some industries. However, it is still one of those complex fields that needs a scientific consolidation and validation. However, in factory environment, it is still needed to assess if Deep Learning or other Machine Learning techniques (including Ensemble learning) will enable the creation of models, which can support tasks such as anomaly detection, fault detection and classification, product quality control (e.g. through computer vision), virtual sensors, and machine behaviour forecast.

c. **SF11 Analytics for Data-Human Interaction of Factory Models.** Data processing analytics for new data-human interaction challenges of existing manufacturing management systems that are mainly driven by human interaction like TPM or FMECA. It is expected that Analytics will enhance such systems avoid weak feedback loops and evolve to RT update including the sharing and detection of good and bad practices.

d. **SF12 Analytics-based decision support in Manufacturing Operations Management.** Integration of manufacturing data into business decision making through advanced prescriptive analytics to make a parametric analysis of business KPIs and estimate error/risk or predictions of this KPIs. The problem of Manufacturing Operations Management can be divided into maintenance, quality and production operations management sub-levels (IEC62264).

e. **SF13 Embedded Analytics.** Specific algorithms of data analytics adapted to embedded hardware that provides insight close to the process/specific machine based on own generated data and data-at-rest sources (e.g. Specific diagnosis of a machine failure based on sensor measurements and expected load schedule).

f. **SF14 Analytics-oriented Manufacturing Simulation Model.** Creation of a hybrid manufacturing simulation model (e.g. model of a machine, cell, line, site) containing analytical and data based models. This will allow simulation models oriented to different scenarios including maintenance and production optimization based on hierarchy of mixed data and analytic models at different levels (e.g. machine, cell, line, site).

g. **SF15 Digital Twin for Analytics.** Creation of a digital twin of the manufacturing line or site with real time and historical data connection to perform optimization and scenarios evaluation (e.g. intermediate stock sizing, reliability).

c4. **Data Protection & Security Challenges.** As a smart factory scenario envisions, the next generation of manufacturing processes will encompass cloud-based data collection and business analytics to facilitate real time decision making. The expected data cloud ecosystem for the factories of the future will be deployed both in public and private cloud infrastructures to reconcile the business needs of the manufacturing organisations of any size. This will drive the evolution of the SRIA Priority 4 “Data Protection Security” towards accommodating the provisions of the upcoming new GDPR to be fully enforced on May 2018. The challenge will be to employ data preservation, through developing data access and protection mechanisms within and across the various departments in a manufacturing organization, as well as the deployment of effective incident response mechanisms for critical CPPS components, which will ensure multi-level data integrity and confidentiality and safeguard the business continuity of the factory level smart manufacturing processes.

a. **SF16. Sensitive Data Privacy in Future Workspaces.** Ensuring the privacy of sensitive data (especially worker-related data) and deciding the best approach
of where (on-site vs cloud) to store these sensitive data.

b. **SF17. Protection against Cyberattacks in Smart Factory.** With the Internet of Things (IoT) becoming a common way to connect across the manufacturing industry, cyber vigilance is more important than ever. Not just individual systems have to be worried about falling victim to malware attacks. An attack stopping a production line or a complete factory is an enormous damage. Automatic methods for detecting intrusions and cyberattacks in specific vulnerable factory equipment (e.g. PLC) need to be investigated.

c. **SF18. Access Control & Data integrity in Smart Factory critical infrastructures.** In factory environment where many data coming from heterogeneous sources has to be integrated, fine-grained access control has to be implemented accordingly to each source. Also data integrity is of key relevance, as it is the basic information used to take decisions (which could be on-the-fly), and could be easily tampered. Therefore, specific solutions to ensure data integrity should be also included to provide robust data analytics solutions for industrial purposes.

d. **SF19 Selective Anonymization in Smart Workspaces.** Decide the optimal approach for which data has to be anonymized (e.g. worker data, products manufactured, production line or cell, ...) to not prevent successful data analytics at site level and analytics-as-a-service by third parties, without hindering performance and data quality.

c5. **Data Visualization Challenges**

a. **SF20. Context-aware Visualization in Smart Workplaces.** Data visualization plays a major role conveying properly information to factory workers. The information provided is context-dependent, so context-aware solutions are needed, for example, to perform maintenance with augmented reality tools (e.g. remote presence) that provide useful data and information to the workers on charge.

b. **SF21. Visual Analytics for Smart Factory decision makers.** Besides, presented data has to be intuitive: detected threats have to be conceptualized and a variety of users (from novice to statistics experts) need to understand patterns detected in the analytical process. There is still a need to enhance visual analytics tools in order to support these tasks, for example for a better visualization of dashboards like balanced scorecards.

c. **SF22 Smart Factory natural language interaction interfaces.** Paradigm change from user-driven information presentation (users need to know which manufacturing data needs) to a more natural-language interaction where user asks for specific manufacturing information (manufacturing line performance) that needs to be extracted from data (manufacturing speed, production quality, breakdowns, ...).

d. **SF23 Cross-domain and data exploration.** The development of common visual interfaces and mash-ups will facilitate the creation of cross-domains application at industrial level. These interfaces shall be complemented with data exploration, navigation and annotation techniques to enable the users to interact with the data presented. Thus, the user will be able to reinforce the learning at same time as get continuous feedback from the system moving the stand-alone learning of the systems to the user-machine bi-directional learning.

e. **SF 24 Simulation and training environments.** Existing learning environments do not fit the needs of future manufacturing work places. The workers on the shop floor need to be trained with contextualized learning technologies. Specific information on problem solving and modelling of the industrial context need to be combined to strengthen the ICT knowledge of the workers. These new technologies will support the implementation of a smart learning environment that enables future workers in smart decision-making and smart production processes.
3.2 Smart Product Lifecycle scenario

The EC and Factories of the Future PPP elaborated in 2015 an innovation roadmap about Collaborative Closed Loop Design for Product-Services in the IoT era\textsuperscript{23}. The basic concept inspiring the roadmap represents a new data-driven collaboration closed loop encompassing all the different phases of a product lifecycle, as depicted here below. Inside this vision, the project identified 7 main research priorities, where priority #5 is named “Big Data for Product-Service design”. This chapter took inspiration from such a roadmap and from the Valencia Summit brainstorming session to elaborate the present paragraph. As indicated in the picture below and taking the production phase as a “watershed” (covered by the Smart Factory grand scenario in this document), we can identify pre-production (innovation-design-engineering) and post-production (usage, maintenance, end-of-life) phases where “Big” datasets could be generated by Digital Products, complementing those generated by the organizations in the value chain (Smart Supply Chain grand scenario in this document).

\begin{itemize}
  \item \textbf{c1. Data Management & Lifecycle Challenges}
  \begin{itemize}
    \item \textbf{a. \textit{SPI Product Design Interoperability}} among heterogeneous data sources in Pre-Production phases. In the highest phases of the product lifecycle, access to very heterogeneous data sources is required and need to be harmonized. Structured data sets characterizing traditional PDM and CAD systems need often to be managed together with semi-structured data coming from the operational life of the product and often with non-structured data, as in the case of brand or sentiment analysis.
    \item \textbf{b. \textit{SP2 Product Operations Data Cleaning and Curation}} in highly distributed data sources in Post-Production phases. Data in motion capture, collection and cleaning in monitoring and possibly diagnosing huge sets (fleets) of real world products in operation poses unprecedented challenges to Big Data science as well as the development of trusted and reliable remote services
  \end{itemize}
\end{itemize}

\textsuperscript{23} The LinkedDesign project (Linked Knowledge in Manufacturing, Engineering and Design for Next-Generation Production, project 284613, active in 2011-2015)
c. **SP3 Product Lifecycle Data Management.** During the whole lifecycle, data from multiple companies needs to be merged. In many cases the confidentiality of the different providers’ data is a challenge for reaching to the maximum knowledge that the manufacturers or even the end-users could obtain.

d. **SP4 Provider-User Product Data Integration**. The combination of the end-user and producer priorities will bring a higher competitive service design as well as an improvement of the development of new products that will fit better the vision of the manufacturer and the end-user.

c2. **Data Processing Architectures Challenges**

a. **SP5 Data at Rest Smart Product Pre-production.** Highly efficient and usually centralized cloud-HPC architectures are needed in order to process huge amounts of data at rest regarding the design and engineering of new products and/or the modelling and simulation of what-if or future behavioural scenarios.

b. **SP6 Data in Motion for Smart Product Post-production.** Highly distributed (fog, edge) Architectures are required for data-in-motion processing of product usage monitoring and control coming from multiple instances of the same product (e.g. remote predictive maintenance).

c3. **Data Analytics Challenges**

a. **SP7 Pre-processing Product Data and deep learning.** The heterogeneity of the captured data from different sources of all the product lifecycle makes extremely difficult the selection of the relevant data. The pre-processing phase is the key point for the success of the system for increasing the quality of the predictive model. Thus, the quality of the service will be improved significantly and as a result the satisfaction of the end-user will increase.

b. **SP8 Real Time Analytics in Smart Products operations.** Over their lifetime smart products produce major volumes of product usage data. While the product is still in use real-time usage data access will allow to adapt and parametrise product functionalities. Furthermore, prescriptive analytics leveraging this product usage data will allow to faster adapt production parameters and design choices for the next product generation.

c. **SP9 Complex Products digital twins alignment.** The integration of sensors and IOT in products (Smart Products, Cyber Physical Systems) enables unprecedented possibilities for predicting systems’ behaviours (e.g. for diagnosis and maintenance). Products modelling and simulation techniques generate and elaborate huge amounts of (mostly structured) data. The alignment of models along the whole lifecycle of a complex product (e.g. as designed, as manufactured, as maintained) requires advanced modelling-simulation techniques.

d. **SP10 Product-Service Systems modelling.** Product-Service Systems (PSSs) are composed artefacts whose behaviour is very difficult to model and simulate owning to the co-presence of mechatronic and ICT systems. New Big Data techniques are required to integrate physical systems modelling with complex software systems.

c4. **Data Protection & Security Challenges**

a. **SP11 Data Confidentiality and IPR in Smart Products pre-production.** Mass customization and extreme personalization of products call for new entities (organisations but also individuals and consumers) to be involved in the design-engineering phases, hindering this way the confidentiality and IP protection of industrial artefacts.
b. **SPI2. Privacy Preservation in Smart Products post-production and operations.** Preserving anonymity (e.g. through differential privacy) of lifecycle usage analytics from individual customer products without hindering the privacy of individual product use from each customer. Balance the enhancement of individual user experience versus the hindering of individual customer market position.

c5. **Data Visualization Challenges**

a. **SPI3 3D visualization of complex Smart Products.** Advances in modelling and simulation of complex products also implies the possibility for engineers to cooperatively work in visually advanced collaboration environments, including synchronization between real-virtual worlds.

b. **SPI4 VR/AR in maintenance and operations of complex Smart Products.** Complex products remote maintenance and training requires human operators to be provided not just with advanced wearables and VR/AR environments, but also with unprecedented at the edge capabilities for data presentation and interaction.

c. **SPI5 Update Smart Products visualization at runtime.** The industrial and manufacturing sectors are usually very volatile. A good visualization can help the user in many aspects: 1) Making data comprehension and interpretation easier, 2) facilitating effective communication among colleagues, and also 3) facilitating further improvements of the system. It means that the visualization may be updated at runtime and users must be informed of changes, as they need to be aware of what is happening in their industrial environment.

d. **SPI6 Highly configurable Smart Products Visualization for the user.** During the whole lifecycle of a product, many different skills of people are needed to draw conclusion of the data. Depending on the phase in which an operator is working, different type of visualization is convenient. Notice that not every operator has the same experience and technological background. Therefore, a configurable visualization is an important challenge in order to adapt the visualization.

e. **SPI7 Product Data visualization by the user.** One of the important tasks in PLM is to ensure the customer or client satisfaction. Different customer might have different emphasis on product. All the operators or customers do not have the same technical skill. Thus, giving the chance to the user to decide how to visualize data gives them the chance for working in a more productive way. Being easier to detect anomalies and avoid production shutdowns and reduce cost in the different phases of the lifecycle of the product.

### 3.3 Smart Supply Chain scenario

Traditional supply chains operate on hybrid models that combine paper- and IT-based processes. Key limitation of any hybrid supply chain model is that information is kept in silos at regional, country, or branch level leading to inconsistent and redundant data during execution of supply chain processes. Today, technologies such as RFID, GPS, and sensors are employed to improve existing hybrid supply chains into more flexible, open, agile, and collaborative digital models. In the Smart Supply Chain Grand Challenge, the SRIA Technical Priorities needs to be extended/reinforced/enhanced/evolved to enable the realization of digital supply chain models that break down rigid organizational structures through integration of different supply chain functions such as product development, procurement, production, maintenance and logistics across geographies and departments. Smart Supply Chains will make available information
handled by distinct digital platforms related to internal information systems such as those of financial governance and KPIs of a manufacturing company, external systems of suppliers, providers, distributors, retailers, and logistics, customer experience systems, as well as operational systems, e.g., IoT-based production systems.

c1. Data Management & Lifecycle Challenges

a. SSC1 Heterogeneous Data in Business Ecosystems. Supply chains and modern manufacturing networks are often configured ad-hoc in the form of temporal alliances in order to satisfy customer orders. Thus, data from numerous new partners, from different sources/databases and in different formats need to be assessed and managed. Traditional ways are struggling to cope with the emerging requirements and new mechanisms are required.

b. SSC2 Cross-enterprise Data Value Chain Management. Novel business model have moved value creation closer to the after-sales phase of the product lifecycle. Product upgrades, maintenance and reconfigurability may now provide additional benefits for the manufacturer. However, in order to maximize this value, access to comprehensive manufacturing parameters and to usage phase data is required.

c. SSC3 Data traceability in value networks. There is a need for track and trace solutions that allow key stakeholders to validate a product (including material and equipment used for production) at various points across the supply chain. This is especially important for time-sensitive products. In particular, Blockchain technology has the potential to transform the supply chain adding transparency, traceability and security to the supply chain.

d. SSC4 Supply Chain collaboration for component, machine and plant providers: There is a need for a collaboration platform for the planning, development, commissioning and operation of machines and systems by sharing engineering information and continuous learning. The key challenge is in consolidating multiple data sets from multiple systems and providing support for bi-directional flow of information across the lifecycle.

e. SSC5 Adaptive and Flexible Supply Chain data Management. Supply-chain networks are not static; they are subject to continuous change. There is a need for an adaptive big data system to provide support for change management by design in order to ensure data sharing between value chain participants.

c2. Data Processing Architectures Challenges

a. SSC6 Vertical Supply Chain Data Integration. In modern supply chains the information exchange among the network partners is not limited to shipping and delivery information. Data from cyber-physical system, IoT environments, monitoring sensors up to sales and marketing data need to be processed in order to eventually form an efficient manufacturing network. New processing architectures for data from shop-floor up to management layer expected to be shared among the manufacturing partners needs to be investigated.

b. SSC7 Real-time supply chain-data processing. Data processing itself is a major challenge for future manufacturing environments. However, it is even much more complicated in manufacturing networks where the volume of in-motion data to be processed increases exponentially. High performance
computing can be employed for processing these data; however issues such as required infrastructure, reference architecture, privacy and security need accordingly to be well-thought in advance.

c3. Data Analytics Challenges

a. SSC8 Data Analytics for Supply Chain Optimisation. Predicting trends in behaviour and the adaptability of an uncertain supply chain environment represents an exponential increase in service level. Advanced demand forecasting models are needed and adaptive models should be applied to respond quickly to information from the environment and to new requirements (e.g., defining flexible delivery points). New channels and sales models should also be addressed. Efficiency gains will require distributed prescriptive analytics for each stakeholder to appropriately react to changes in supply (e.g. machine failures, part scarcity, price surges) and demand (e.g. product hypes, marketing campaigns, etc.). Real-time updates on performance indicators, including (Correlation of) real-time analytics across multiple points in the supply chain in order to detect discrepancy in the metrics or a sudden change. Metrics could include supplier performance, product transit monitoring, etc. Data analytics for workforce management, including demand-driven capacity resource planning within the facility based on real-time detection of fluctuations in supply and demand patterns. Real-time resource analysis, including, detection of underutilization or over utilization of resources across the value chain.

b. SSC9 Supply Chain condition and risk analysis. Unexpected events, including also natural events, can significantly alter the efficiency of supply chains and/or even completely stall it. Data analytics should be used: i) to predict the potential negative effects of such events before they actually distort the supply chain in operation and ii) to offer the most suitable alternatives.

c. SSC10 Analytics-based decision support in Business Ecosystems. Real-time updates on performance indicators: (Correlation of) real-time analytics across multiple points in the supply chain in order to detect discrepancy in the metrics or a sudden change. Metrics could include supplier performance, product transit monitoring, etc.

d. SSC11 Data analytics for Supply Chain workforce management: Demand-driven capacity resource planning within the facility based on real-time detection of fluctuations in supply and demand patterns. Real-time resource analysis: Detection of underutilization or over utilization of resources across the value chain.

e. SSC12 Prescriptive Maintenance in Production Chains. The current trend to prescriptive maintenance analytics for machines promises benefits on a plant level but already requires considerable amounts of multi-modal real-time data streams, probably coming from similar machines across the production chains or in similar sites. The next step to improve efficiency levels is then to coordinate prescriptive maintenance actions across the complete production chain (both within an integrated company as well as a multi-sided product supply chain or product network). This has multiplicative effects on the requirements on data throughput and data sources.
c4. Data Protection & Security Challenges
The alliances created in the form of supply chains need to be protected regarding also their privacy and security dimensions. Such alliances, in order to operate as efficiently as possible, require heavy sharing of data. To be sustainable and long-lasting though, privacy and security issues related to data sharing need to be tackled decisively. Specific, sensitive parts of data from shop-floor, machine condition parameters, demand forecasts, production orders, quality inspections, etc. need to be protected according to the data owner’s specifications. State-of-the-art security protocols for software and hardware tools need to be installed and operated. Reference Architectures such as RAMI 4.0 should make security an integral part from the value stream to hierarchical levels and layers.

a. SSC13 Cybersecurity and Trust in Agile Value Networks. Cybersecurity and trust are prerequisites for reliable Smart Supply Chains. Smart Supply Chains should pay special attention to the security of networked systems and focus on SMEs and their needs. In order to achieve value creation through Smart Supply Chains, secure communications in digital transactions across involved companies should be safeguarded. Trustworthiness is also a key challenge from the perspective of assessing the inclusion of a company in a value network or not. Moreover, methods and models that assess the security level of Smart Supply Chains as a whole are needed. Finally, secure identities are essential for secured Smart Supply Chains for ensuring data integrity during data exchanges within and across companies involved in the chain.

b. SSC14 VR/AR Technologies in Supply Chain Integration. Already employed for various applications, VR/AR solutions can be a useful tool at the hands of supply chain integrators. The distribution of processes to many different nodes of the supply chain often introduces a difficult orchestration of various manufacturing aspects such as quality assurance, process compliance, maintenance activities, etc. VR/AR technology can significantly support overcoming several of these activities.

b. SSC15 Customised User Interface in Business Ecosystems. In extended supply chains, various types of actors are involved from shop-floor to management and along the various companies involved to the supply chain. Thus, user interface needs to be accustomed according to each type of user. Different ergonomics, different devices and different information should be shown to the shop-floor user in relation to the business analytics that needs to be shown to the demand forecaster and to the management team. Accordingly, different interfaces could be developed for Tier-1 suppliers than to Tier-n suppliers, based on their preferences.
4 DATA-DRIVEN PATHWAYS TO 2025 CONNECTED FACTORIES SCENARIOS

In correspondence with the definition of the Connected Factories pathways to 2025 scenarios, this Chapter 4 (to be developed in Spring-Summer 2018) intends to implement the “Data” viewpoint of the 2025 migration pathways, will also consider lighthouse contributions from the BOOST 4.0 project, to be started in January 2018, under the coordination of INNOVALIA.

The tentative structure for this chapter is:

• Increasing TRL of Big Data Analytics Solutions
• Implementing early adoption champions
• Experimenting Lighthouse projects
• Extracting best practices and implementation guidelines
• Data-driven Business models migration paths
• Data-driven Skills / Competencies / Education migration paths
• Data-driven Privacy / Security / Legal migration paths

As Lessons learned from 2017 activities, we leave some considerations expressed by the three responsible persons in charge of the three scenarios of Smart Factory, Smart Product Lifecycle and Smart Supply Chain.

4.1 Fine tuning Smart Factory challenges vs. CF 2025 Autonomous Factories persona

The Autonomous Factories persona is mainly related to the smart factory challenge. Specific data analytics challenges defined there like SF10 (machine and deep learning) and SF15 (digital twin) are tightly coupled with the idea of an optimized and sustainable autonomous factory. In addition to that, nearly all the visualization challenges (e.g. SF20 Context-aware visualization) are focused with the end user in mind, and hence, contributing to the idea of workspaces with the worker as its centre (human-in-the-loop). In an upcoming autonomous factory, workers will focus their skills in process and
products and machinery skills will be less relevant. It’s a comeback to craftsmanship or artisan 4.0.

4.2 Fine tuning Smart Supply Chain challenges vs. CF 2025 Hyper-connected Factories persona

The SMI Smart Supply Chain Grant Challenge is in a very large degree at the same direction as the Hyper-connected Factories EFFRA persona. They both address the issue of effective and efficient coordination and integration of various stakeholders involved in manufacturing production. It appears that EFFRA Hyper-connected persona puts the emphasis on the coordination of shop-floors of manufacturing entities involved in integrated supply chains whereas SMI Smart Supply Chain Grand Challenge takes a more holistic approach to include different supply chain functions such as product development, procurement, production, maintenance and logistics. Nevertheless, both SMI Smart Supply Chain Grant Challenge and Hyper-connected Factories EFFRA persona identify their challenges in reference to the dimensions identified in the BDVA reference architecture, including data management, data protection, data processing, data analytics and data visualization. One aspect that was not considered by the corresponding EFFRA persona and which was extensively discussed in the AG22 workshop is related to the challenge of how to identify and select the appropriate members of an integrated supply chain, including subcontractors, suppliers, etc. The use of historical data related to the relevance and past performance of candidate supply chain members as well as use of simulation and decision support technology emerged as very appropriate for both the SMI Smart Supply Chain Grant Challenge and the Hyper-connected Factories EFFRA persona.

4.3 Fine tuning Smart Product Lifecycle challenges vs, CF 2025 Collaborative Product-Service Factories persona

The CF CSA “Product Service Factories” persona originated from a cluster of H2020 Research and Innovation actions called PSS Cluster (Product Service System). The main aim of the cluster is a paradigm shift for the manufacturing industry, from a mere product-oriented to a service-oriented market approach. The CF CSA persona represent the 2025 projection of such a transition where physical products are still manufactured in Europe, but customers and users mostly perceive the outcome of their services. Short term examples concern selling mobility services rather than vehicles or selling copies
rather than photocopiers, while longer term visions embrace other business cases, such as selling dressing services rather than clothes or selling holes rather than machine tools. On the basis of these 2025 scenarios, technical and non-technical challenges are then identified and described.

The BDVA Smart Product Grand Challenge approach is generated inside a technology-driven community and therefore focuses on the technological challenges related to data economy applied to the Product lifecycle. Examples are scenarios where product data owners, providers and consumers are linked in collaborative business processes under well defined privacy and data confidentiality borders. The convergence of such visions (the business innovation vs. the technological innovation) is in our opinion the key challenge in this domain: how much the tremendous innovation push given by BD technologies could enable and support new business models, creating new jobs and compensating the jobs reduction due to the traditional Industry 4.0 interpretation of “factory automation”. Will “data-driven product-related services” revolutionise our 2025 society not just with new Smart Product Service Systems (e.g. autonomous car or cognitive machines), but mostly with disruptive business models and new jobs and professions?
5 CONCLUSIONS AND FUTURE OUTLOOK

Challenges identified in this first version of position paper set the tone for the upcoming research needs in different areas.

In the Smart Factory scenario the focus is on integration of multiple sources of data coming not only from the shop floor but also from the offices, traditionally separated in Industry 3.0. Interoperability of existing information systems and the challenge of integrating disruptive IoT technologies are major trials in the area of data management. Closer to the needs of a Smart Factory, the analytics challenges are focused on prescriptive analytics as tools for an optimal decision-making process at the manufacturing operations management site including the optimization through the evolved concept of digital twin.

In Smart Products domain, the full adoption of Data Processing and Analytics technologies will enable a next generation of Smart Products but mostly a broad ecosystem of Smart Services with unprecedented business opportunities for manufacturing and ICT industries.

Smart Supply Chains make possible the design and execution of end-to-end production chains and of centralized services that automate business processes, optimize offshoring and outsourcing, and offer increased visibility of corporate assets through, for example, integration of operational and financial data. The ultimate goal of a Smart Supply Chain is the complete execution of an end-to-end supply chain process without the need for manual intervention or re-keying of information, resulting in improved reliability, agility and effectiveness of production processes.

Next version of this Position Paper will be closely related to the progress status of our BDVA Lighthouse project in the domain of Manufacturing (BOOST 4.0), which is going to start on January 1st 2018. This new release (2.0) will firstly consider the SRIA 4.0 and its novel challenges and priorities as well as the further evolution of the CF CSA pathways to 2025 scenarios in the domain of Smart Connected Factories.

The future release 2.0 will also address new evolutions of the Digitising EU Industry Working Group 2 about Digital Platforms and in particular those related to Industrial Data Platforms derived from Data-driven Reference Architectures such as the IIRA 1.8 and its concept of layered databuses.

Finally, the release 2.0 will also address the non-technical challenges (e.g. skills, regulations, privacy-security) which have not been properly addressed in this 1.0 release.
This position paper is the result of the collaborative work done in the context of the Smart Manufacturing Group in the Big Data Value Association.

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In particular, we wish to mention EFFRA’s contributions to this discussion paper, especially focussing on alignment and interoperability between BDVA cPPP strategic research agenda and FoF cPPP 2025 Connected Factories scenarios and pathways.

In addition to these explicitly listed contributors it worth to mention that the current members of the group are more than 70 and many of them provided relevant content and support during the various meeting.
Contributions from Valencia Summit<sup>24</sup> (Nov 29th 2016)

Here are reported the tables created starting from the contributions collected during the Valencia Summit. The three tables refers to the three gran scenarios considered.

## Smart Factory

<table>
<thead>
<tr>
<th></th>
<th>Group 1G</th>
<th>roup 2G</th>
<th>roup 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data Management &amp; Lifecycle</strong></td>
<td>• Combining data from all production lines</td>
<td>• Data Quality; uniform sample, good data description, missing values</td>
<td>• Standardize integration &amp; communication of CPS</td>
</tr>
<tr>
<td></td>
<td>• Data drive people; cultural change</td>
<td>• Semantic interoperability; machine data; sensitive data</td>
<td></td>
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<tr>
<td><strong>Data Processing Architectures</strong></td>
<td>• Sensor monitoring data availability</td>
<td>• Data compression</td>
<td>• Real time streaming</td>
</tr>
<tr>
<td></td>
<td>• Real-time data processing</td>
<td>• Stream (reliable) processing</td>
<td>• Hybrid cloud</td>
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<td></td>
<td>• Cloud vs on-premises analytics</td>
<td>• Cloud federation</td>
<td></td>
</tr>
<tr>
<td><strong>Data Analytics, Models Simulation</strong></td>
<td>• Model based diagnosis anomaly detection</td>
<td>• Contextualized data bundles</td>
<td>• Detecting patterns of good practice</td>
</tr>
<tr>
<td></td>
<td>• Predictive maintenance</td>
<td>• Pattern recognition</td>
<td>• Predictive &amp; prescriptive models</td>
</tr>
<tr>
<td></td>
<td>• Process optimization (Factory line); change curve</td>
<td>• Deep learning methods &amp; techniques</td>
<td></td>
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<tr>
<td></td>
<td>• Prescriptive maintenance</td>
<td>• Prescriptive maintenance</td>
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</tr>
<tr>
<td><strong>Data Protection Security</strong></td>
<td>• Cybersecurity; SCADA</td>
<td>• Fine grained access control</td>
<td>• Hybrid cloud</td>
</tr>
<tr>
<td></td>
<td>• Connecting data access department OP - IT</td>
<td>• IoT Security: Field bus level</td>
<td>• Privacy of worker data</td>
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<tr>
<td></td>
<td>• Sharing training data</td>
<td>• Data safety</td>
<td></td>
</tr>
<tr>
<td><strong>Data Visualization</strong></td>
<td>• Combining data from all production lines</td>
<td>• Cloud federation</td>
<td>• Machine adapts to human</td>
</tr>
<tr>
<td></td>
<td>• Intuitive data presentation</td>
<td></td>
<td>• Context aware information distribution</td>
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<tr>
<td></td>
<td>• Augmented reality; man-machine interaction</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>• Context-aware data visualization</td>
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<sup>24</sup> [http://www.bdva.eu/?q=valencia-summit](http://www.bdva.eu/?q=valencia-summit)

Annex Editorial Team and Contributors

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**Contributions from Valencia Summit**

- **Group 1G**: Combining data from all production lines, Data Quality; uniform sample, good data description, missing values.
- **roup 2G**: Data compression, Stream (reliable) processing, Cloud federation, Scalable & elastic processing architecture.
- **roup 3**: Real time streaming, Hybrid cloud.

---

**Data Management & Lifecycle**

- Combining data from all production lines, Data drive people; cultural change, Semantic interoperability; machine data; sensitive data.

---

**Data Processing Architectures**

- Sensor monitoring data availability, Real-time data processing, Cloud vs on-premises analytics.

---

**Data Analytics, Models Simulation**

- Model based diagnosis anomaly detection, Predictive maintenance, Process optimization (Factory line); change curve, Prescriptive maintenance.

---

**Data Protection Security**

- Cybersecurity; SCADA, Connecting data access department OP - IT, Sharing training data.

---

**Data Visualization**

- Combining data from all production lines, Intuitive data presentation, Augmented reality; man-machine interaction, Context-aware data visualization.
## Smart Supply Chain

<table>
<thead>
<tr>
<th>Data Management &amp; Lifecycle</th>
<th>Group 1G</th>
<th>roup 2G</th>
<th>roup 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Standardisation</td>
<td>• Integration supply data with on-premise data</td>
<td>• Blockchain</td>
<td></td>
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<tr>
<td>• Semantic modeling</td>
<td>• Sharing data in the whole chain</td>
<td>• Share parts, Continuous improvement through data exchange from user to supplier</td>
<td></td>
</tr>
<tr>
<td>• Blockchain for part;</td>
<td>• Data value chain; lifecycle management</td>
<td>• Interoperability</td>
<td></td>
</tr>
<tr>
<td>history / versioning; etc</td>
<td>• Global data; single data marke</td>
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<tr>
<td>-&gt; part certification</td>
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<table>
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<tr>
<th>Data Processing Architectures</th>
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<tbody>
<tr>
<td>• Cloud, Paas; DaaS Model</td>
<td>• Heterogeneous data processing &amp; preparation</td>
<td></td>
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<tr>
<td>• Cooperative business model</td>
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<table>
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<tr>
<th>Data Analytics, Models Simulation</th>
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</thead>
<tbody>
<tr>
<td>• Digitized-mashed supply networks</td>
<td>• Identify relevant data</td>
<td>• Supplier selection &amp; continuous improvement</td>
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<tr>
<td></td>
<td>• Predictive delivery time</td>
<td>• Predictive model for interaction among suppliers</td>
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<td></td>
<td>• Predictive stocks</td>
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<table>
<thead>
<tr>
<th>Data Protection Security</th>
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<tbody>
<tr>
<td>• Privacy by design</td>
<td>• Sharing data in the whole value chain</td>
<td>• Confidentiality</td>
<td></td>
</tr>
<tr>
<td>• Privacy aware SLA;</td>
<td>• Design collaboratively</td>
<td></td>
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<tr>
<td>digital contents</td>
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<tr>
<td>• Anonymization algorithms</td>
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<tr>
<th>Data Visualization</th>
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<tbody>
<tr>
<td>• BPM; collaborative BPM visualization</td>
<td>• Presenting industrial data to business analysts</td>
<td>• Visualization of the supply chain</td>
<td></td>
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<tr>
<td>• Event discovery &amp; propagation</td>
<td>• designing collaboratively</td>
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</table>
**Smart Product Lifecycle**

<table>
<thead>
<tr>
<th>Data Management &amp; Lifecycle</th>
<th>Group 1G</th>
<th>Group 2G</th>
<th>Group 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Incentive to share; usage data enabling business models</td>
<td>• Data quality, curation, cleaning, etc.</td>
<td>• Interoperability</td>
<td></td>
</tr>
<tr>
<td>• Just in time customization</td>
<td>• Management of data from different providers/vendors</td>
<td>• Distributed data</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Data Processing Architectures</th>
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<th></th>
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</thead>
<tbody>
<tr>
<td>• Product tracking &amp; tracing</td>
<td>• Big Data architecture</td>
<td>• Blockchain</td>
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<tr>
<td>• Living Labs</td>
<td>• Remote monitoring</td>
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<table>
<thead>
<tr>
<th>Data Analytics, Models Simulation</th>
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<tbody>
<tr>
<td>• Root cause analysis algorithms</td>
<td>• Root cause analysis</td>
<td>• Digital twin lifecycle</td>
<td></td>
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<tr>
<td>• Remaining useful life algorithms</td>
<td>• Data in the end of life</td>
<td>• Predictive models</td>
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<tr>
<td>• Post sale service; product service</td>
<td>• Simulation of processes</td>
<td>• Cause &amp; effect</td>
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<tr>
<td>• Hardware in the loop; Digital twin</td>
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<tr>
<td>• Heavy product usage data to optimize</td>
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<tr>
<td>• Predictive maintenance (for machine tools or manufacturing assets)</td>
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<tbody>
<tr>
<td>• Privacy by default</td>
<td>• Privacy preserving product tracker</td>
<td>• Data sovereignty</td>
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<tr>
<td></td>
<td></td>
<td>• Cybersecurity</td>
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<table>
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<tr>
<th>Data Visualization</th>
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</thead>
<tbody>
<tr>
<td>• Product delivery as part of CRM</td>
<td>• Visualization of remote monitoring information</td>
<td>• Immersive collaborative environment (linked to digital twin)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Data coming from different sources (piece producer, specialist, assembler)</td>
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