14

Tools and Techniques for Digital Automation Solutions Certification

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The digitisation and adoption of increasingly autonomous digital capabilities in the Factory 4.0 shopfloor demands that a large number of technologies need to be integrated, while the differential value of European manufacturing, i.e. security and safety, is ensured. Industry 4.0 puts additional pressure in small and medium-sized enterprises (SMEs) in terms of navigating standards, norms, and platforms to fulfil their business ambition. The Digital Shopfloor Alliance emerges as a multisided ecosystem that provides an integrated approach and a manufacturing-centric view on the digital transformation of automation solutions. This chapter introduces a certification framework for faster system integration and validated solution deployment. The main inputs from our approach to modular Plug & Produce autonomous factory environments & Validation & Verification (V&V) framework. This chapter also discusses how a validation and verification framework in combination with certified components could become key in the development of open digital shopfloors with future digital ability extensibility, controlled return of investment on Industry 4.0 solutions. This paper discusses also how such an approach can create a virtuous cycle for digital platform ecosystems such as FIWARE for smart industry, IDSA or more commercially driven ones such as Leonardo, Mindsphere, 3DExperience, Bosch IoT Suite, Bluemix, Watson, Predix, and M3.

14.1 Introduction

In the context of Industry 4.0 and Cyber Physical Production Systems (CPPS), markets, business models, manufacturing processes, and other challenges along the value chain are all changing at an increasing speed in an increasingly interconnected world, where future workplace will present increased mobility, collaboration across humans, robots and products with in-built plug & produce capabilities. Current practice is such that a production system is designed and optimized to execute the exact same process over and over again.

The planning and control of production systems has become increasingly complex regarding flexibility and productivity, as well as the decreasing predictability of processes. The full potential of open and smart CPPS is yet to be fully realized in the context of cognitive autonomous production systems. In an autonomous production scenario, as the one proposed by Digital Shopfloor Alliance (DSA) [1], the manufacturing systems will have the flexibility to adjust and optimize for each run of the task. Small and medium-sized enterprises (SMEs) face additional challenges to the implementation of "cloudified" automation processes. While the building blocks for digital automation are available, it is up to the SMEs to align, connect, and integrate them together to meet the needs of their individual advanced manufacturing processes. Moreover, SMEs face difficulties to make decisions on the strategic automation investments that will boost their business strategy.

Within the AUTOWARE project [3], new digital technologies including reliable wireless communications, fog computing, reconfigurable and collaborative robotics, modular production lines, augmented virtuality, machine learning, cognitive autonomous systems, etc. are being made ready as manufacturing technical enablers for their application in smart factories. Special attention is paid to the interoperability of these new technologies between each other and with legacy devices and information systems on the factory floor, as well as to providing reliable, fast integration, and cost-effective customized digital automation solutions. To achieve these goals, the focus has been set on open platforms, protocols, and interfaces, providing a Reference Architecture for the factory automation, and on a specific certification framework, for the validation not only of individual components but of deployed solutions for specific purposes, to help SMEs and other manufacturing companies to access and integrate new digital technologies in their production processes.

This chapter aims to review the certification framework, tools and techniques proposed within the global vision of DSA ecosystem, with a clear

focus on enabling the digital transformation process on manufacturing SMEs through the adoption of digital automation solutions in their shopfloors.

Section 14.2 presents Safety as a main asset of European manufacturing industry that is challenged by autonomous operations and which represents a big challenge for SMEs in terms of regulation and level of integration across technologies and platforms. Section 14.3 presents a global vision of the DSA initiative and ecosystem, while Section 14.4 presents the alignment of DSA ecosystem with AUTOWARE Reference Architecture (RA), Technical and Usability Enablers to leverage digital abilities in the Shopfloor. This chapter also introduces the main strategic services to be provided. Next, Section 14.5 presents the V&V framework and component/system certification that constitutes the basis for the Digital Automation Technologies Validation framework. Section 14.6 elaborates in-depth DSA ecosystem players, approach, benefits, and services towards a win-win model for the multi-sided ecosystem.

14.2 Digital Automation Safety Challenges

SMEs are a focal point in shaping enterprise policy in the European Union (EU). In order to preserve and increase competitiveness in the global market, the SMEs need to digitalize their processes through the adoption of CPPS technologies in Digital Automation Solutions. After the analysis of new trends and challenges in SME manufacturing towards digital production paradigm by accessing new CPPS technologies and tools, we focused on new emerging technologies and paradigms such as Internet of Things, Industry 4.0, machine learning and artificial intelligence, robotics, Virtual/Augmented Reality, cloud computing, Cyber Physical Production Systems, and particularly on their impact on the SME production.

All these technologies that can be deployed in SME manufacturing and low-volume production are beginning to emerge and were proved to be beneficial to gain a competitive edge. However, the adoption of these technologies in actual SME production is still limited and needs to be sped up. Two main barriers preventing wider usage of these digital solutions were identified. On the end-users' side, the lack of knowledge and the time and cost constraints are dominant. On the supply side, there is a need to move from application orientation towards integrated solutions that will better support small enterprises, both in terms of customized and flexible applications. An effective measure to overcome problems related with the application of new smart technologies in the SMEs is to provide easy access to them through an ecosystem with integrated tools and techniques for Digital Automation

Solutions certification. This section forms a report on identified demands and challenges faced by manufacturing SMEs with regard to safety and certification areas.

The fourth Industrial Revolution for EU Manufacturing Industry **(Industry 4.0)** is generally associated with the full adoption of digital technologies in production and for having an exclusive focus on smart factory automation. This was at the basis of the Industrie 4.0 initiative in Germany when it started back in 2011. However, the most recent evolutions of the Industry 4.0 paradigm have considerably extended the scope and characteristics of Industry 4.0 projects, embracing and addressing new ways of conceiving products, production, and running manufacturing-oriented business models. During the **World Manufacturing Forum** 2016 in Barcelona, Roland Berger [1] presented the main transformations of new Industry 4.0, such as from *mass production* to *mass customization*, from *volume scale effect* to localized and *flexible production units*, from *make to stock* static and hierarchical supply chains to *make to order* dynamic reverse supply networks, from *product oriented* economy to *service and experience economy*, from hard *Taylorism-driven workplaces* to attractive and *adaptive workspaces*. The result of materializing the newly identified **"Industry 4.0"** is the identification of characteristics, where extensions of the traditional Smart Production model (well represented by the RAMI 4.0 Reference Architecture) are required.

The Digital Shopfloor Alliance (DSA) is a manufacturing-driven approach to digital transformation and it is the response to such new production paradigms. Production lines are in the process of migrating from production lines into autonomous work cell environments where increased autonomy and flexibility in operations are the key features. However, such flexible environments yet need to retain the same safety features as the traditional production chains. Hence, there is a demand for the development of digital platforms that will support the engineering, commissioning, and safe and secure operation of such advanced autonomous production strategies.

The smart factories of the future are built on a modular basis. With standardized interfaces and cutting-edge information technology, they enable the establishment of flexible automated manufacturing reflecting the "plug and produce" and autonomous production principles. Initiatives such as Industry 4.0 and the European digital shopfloor alliance (DSA) are developing the concept of **modular certification scheme and control in real time** to include a specific approach which takes into account all specific requirements for adaptive, configurable systems. All plant

manufacturers need to develop a safety and security concept for their equipment and confirm that their equipment complies with legal requirements. Modular certification and self-assessment schemes are critical elements in the operation of autonomous equipment variants. This ensures that the equipment is automatically certified when a module is replaced, or a new line configuration is set by the integration of autonomous equipment in modular manufacturing settings and thus continues to be in conformity with the legal requirements and/or the standard.

Currently, industrial automation is a consolidated reality, with approximately 90 per cent of machines in factories being unconnected. These isolated and static systems mean that product safety (functional safety and security) can be comfortably assessed. However, the connected world of Industry 4.0's smart factories adds a new dimension of complexity in terms of machinery and production line safety challenges. IoT connects people and machines, enabling bidirectional flow of information and real-time decisions. Its diffusion is now accelerating with the reduction in size and price of the sensors, and with the need for the exchange of large amount of data. In today's static machinery environment, the configuration of machines and machine modules in the production line is completely known at the starting point of the system design. However, if substantial changes are made, a new conformity assessment may be required. It is an employer's responsibility to ensure that all machinery meet the requirements of the Machinery Directive and Provision and Use of Work Equipment Regulations (PUWER), of which risk assessments are an essential ingredient. Therefore, if a machine has a substantial change made, a full CE marking and assessment must be completed before it can be returned to service. Any configuration change in the production line requires re-certification of the whole facility.

However, the dynamic approach of Industry 4.0's autonomous robotic systems means that with a simple press of a button, easily configurable machinery and production lines can be instantly changed. As it is the original configuration that is risk assessed, such instant updates to machinery mean that the time-hungry, the traditional approach of "risk assessment as you make changes" will become obsolete. The risk assessment process therefore needs to be modified to meet the demands of the more dynamic Industry 4.0 approach. This would mean that all possible configurations of machines and machine modules would be dynamically validated during the change of the production line. Each new configuration would be assessed in real time, based on digital models of the real behavior of each configuration, which would be based upon the machinery manufacturer's

correct (and trusted) data. The result would be a rapidly issued digital compliance certificate.

This Section discuss the challenges that such approach would entail from the context of safe operation of modular manufacturing, reconfigurable cells, and collaborative robotic scenarios.

14.2.1 Workplace Safety and Certification According to the DGUV

The Deutsche Gesetzliche Unfallversicherung (DGUV) is the German statutory accident insurance. The DGUV has published a requirements document that addresses workplace safety and certification aspects concerning collaborative robots. On conventional industrial robot systems, safeguards, such as protective fences and light curtains, prevent the access of people to hazardous areas. Collaborative robot systems, however, represent a link between fully automated systems and manual workplaces. The fact that Smart Manufacturing tends towards smaller batch sizes is one reason why collaborative robots are taking on greater significance. In an almost fenceless operation, which is dependent on the type of collaboration, the robot can thus support workers on manual tasks. This relieves the worker which is of benefit to the company managers in the medium to long term, since it results in less downtimes and an enhanced health situation of employees.

The DGUV provides the information "Collaborative robot systems – Design of systems with Power and Force Limiting" function for free download [4]. This information is intended to give an initial overview on the procedures when planning collaborative robot systems. The implementation of the AUTOWARE Use Case 3 – Industrial Cooperative Assembly of Pneumatic Cylinders necessitates the compliance with the workplace safety standards. In doing so, the DGUV requirements are considered in the design of the collaborative workspace. The fulfilment of the requirements provided by the DGUV is an essential prerequisite for the legal operation of collaborative robot systems in factories and their certification.

14.2.2 Industrial Robots Safety According to ISO 10218-1:2011 & ISO 10218-2:2011

The main current, i.e. published, standards regarding security as relevant to industrial robots (in contrast to personal care robots), are ISO 10218-1:2011 and ISO 10218-2:2011. The ISO 10218-1:2011, "Robots and robotic devices – Safety requirements for industrial robots – Part 1: Robots"

[5] specifies requirements and guidelines for the inherent safe design, protective measures, and information for use of industrial robots. It describes the basic hazards associated with robots and provides requirements to eliminate, or adequately reduce, the risks associated with these hazards.

The ISO 10281-2:2011, "Robots and robotic devices – Safety requirements for industrial robots – Part 2: Robot systems and integration," specifies safety requirements for the integration of industrial robots and industrial robot systems as defined in ISO 10218-1 with industrial robot cell(s) [6]. The integration includes the following:

- the design, manufacturing, installation, operation, maintenance, and decommissioning of the industrial robot system or cell;
- necessary information for the design, manufacturing, installation, operation, maintenance, and decommissioning of the industrial robot system or cell; and
- component devices of the industrial robot system or cell.

ISO 10218-2:2011 describes the basic hazards and hazardous situations identified with these systems, and it also provides requirements to eliminate or adequately reduce the risks associated with these hazards. It also specifies requirements for the industrial robot system as part of an integrated manufacturing system. The design of experiments in AUTOWARE JSI reconfigurable robotics cell will take into account these two standards.

14.2.3 Collaborative Robots Safety According to ISO/TS 15066:2016

As flexible, fast reconfigurable robot tasks nowadays often include collaborative activity between human operators and robots (and such application will only increase), a very important standard we take into account is ISO/TS 15066:2016, "Robots and robotic devices – Collaborative robots." ISO/TS 15066:2016 specifies the safety requirements for the collaborative industrial robot systems and the work environment. It supplements the requirements and guidance on collaborative industrial robot operation given in ISO 10218-1 and 10218-2. Two main newly introduced points are that 1) in essence, we have to obtain a safe collaborative application – the robot per se is not enough to guarantee a safe robot application and 2) the safety is specified by limited physical values that can be exerted in relation to humans (e.g. limited contact forces) rather solely by adoption of some technical type of safety solution. JSI reconfigurable robotics cell makes use of robots certified for collaboration with humans.

14.3 DSA Ecosystem Vision

Until recently, digital products for SME businesses were nothing more than products for large enterprises, with reduced functionalities. This has resulted in a first opportunistic rather than the strategic adoption of CPPS by SMEs, which handicaps the sustainable growth of such industries. To accelerate the adoption of CPPS by SMEs as producers of CPPS or as users of CPPS, the barriers to translate the benefits of CPPS into core business values, need to be reduced.

There are several European initiatives under the framework of FoF-11 H2020 DEI call that are working on providing platforms and solutions for the acceleration of digital automation engineering processes and the development of the necessary building blocks to realize full support to fog/cloud-based manufacturing solution in the context of Industry 4.0.

Based on the common approach of H2020 AUTOWARE [3], DAEDALUS [7], and FAR-EDGE [8] projects for the European digitisation of SMEs, the DSA has been defined with the common objective of providing reliable, cost-effective integrated solutions to support small enterprises, both in terms of customized and flexible applications.

The DSA is an open ecosystem of certified applications that will allow the ecosystem partners to access different components to develop smart digital automation solutions (the so-called shopfloor digital abilities) for their manufacturing processes. This ecosystem is aimed at reducing the cost, time, and effort required for the deployment of digital automation system on the basis of validated & verified components for specific configurations and operation profiles.

The three projects provide a complete CPPS solution allowing SMEs to access all the different components in order to develop digital automation cognitive solutions for their manufacturing processes. AUTOWARE provides a complete CPPS ecosystem, including a reference architecture that perfectly fits with FAR-EDGE architecture based on splitting the computing in the field (considering the decentralized automated shopfloor defined inside DAEDALUS), the edge, and the cloud. DAEDALUS also defines an intermediate layer (Ledger) to synchronize and orchestrate the local processes. Finally, AUTOWARE also enriches the different technical enablers to make easier the adoption of CPPS by SMEs as well as reliable communications and data distribution processes.

This combined solution reduces the complexity of the access to the different isolated tools significantly and speed up the process by which multi-sided partners can meet and work together. Moreover, the creation of

added value products and services by device producers, machine builders, systems integrators, and application developers will go beyond the current limits of manufacturing control systems, allowing the development of innovative solutions for the design, engineering, production, and maintenance of plants' automation.

AUTOWARE has defined a complete open framework including a novel modular, scalable, and responsive Reference Architecture (RA) for the factory automation, defining methods and models for the synchronization of the digital and real world based on standards and certified components. AUTOWARE RA aligns several cognitive manufacturing technical enablers, which are complemented by usability enablers, thereby making it easy to access and operate by the manufacturing SMEs. The third key element in the ecosystem is the certification framework for the fast integration and customization of digital automation solutions.

The DSA proposes to go beyond a mere marketplace, (see Figure 14.1) and provide an integrated approach that on the development side ensures the provisioning of qualified CPPS components, certified systems and solutions thereby reducing the integration and customization costs. Moreover, the operational conditions and performance expected from Systems of Systems (SoS) operations can be managed in a controlled manner that ensures that machine and co-botic EU safety requirements can be addressed in the context of increased flexibility and system reconfiguration. On the demand side, the acquisition and operation costs are reduced based on shorter deployment cycles and customization on the basis of certified components already qualified with concrete working and development conditions validated for a specific purpose.

DSA ecosystem aim to ease the digital transformation process for manufacturing SMEs and it is based on an integrated approach, aligned with AUTOWARE goals of leveraging autonomous solutions through digital abilities, which includes a set of tools, techniques and services:

- **DSA experts network** helping manufacturing SMEs to define and evaluate their digital transformation strategy, and providing support for its implementation;
- **DSA RA**, aligned with widely established open HW and open platforms technologies, based on AUTOWARE RA;
- the provisioning of **DSA compliant:**
    - **Technological components** (from well-known technology providers and aligned to open HW, SW and platforms);
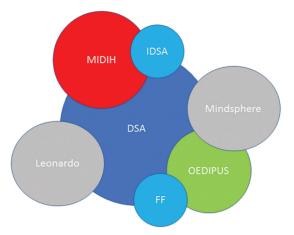
Figure 14.1   DSA manufacturing multisided ecosystem.

- ○ **Core Products** (architectural, functional, non-functional, normative and S&S compliant, validated for a purpose VPP);
- ○ **Certified solutions** (safety compliant: certified Components and Core Product validated for a specific application/service); and
- ○ **Validated deployments,** developed by trained professional integrators, for SME's customized automation solutions;
- access to trial-oriented **testbeds and neutral facilities** to offer a quick access and hands-on demonstrations of already validated solutions;
- the **Digital Automation Technology Validation (DATV) framework** for technologies, tools and services validation for a specific use under certain conditions, normatives, and standards based on AUTOWARE V&V enablers; and
- the access to an **homologated professional network** of integrators trained by Core Products owners and expertise in DSA technologies.

This approach enables DSA to offer **both top-down and bottom-up vision to implement safe digital transformation strategies and secure I4.0 digital automation systems in manufacturing SMEs.** In contrast to the top-down vision of known large technology providers focused on its core products or focused on its core architecture; DSA lowers the barrier that hinders the adoption of the latest technologies for the implementation of digital shopfloors in manufacturing SMEs.

DSA approach will focus on easing and enabling the digital transformation strategy for key application areas & services of competitive interest for manufacturing SMEs:

Figure 14.2 DSA ecosystem objectives.

- Energy efficient manufacturing services;
- condition-based monitoring & predictive maintenance services;
- zero defect manufacturing services;
- factory logistics management services;
- workplace augmentation, training, and human decision support services;
- digital twin modeling and simulation services; and
- Big Data Analytics for production planning and optimisation services.

The DSA bottom-up vision, based on the access to DATV-validated Core Products and Solutions, DSA services, and professionals, helps fulfil the DSA main goals of reducing the cost, time, and effort required to implement safe digital processes and products and secure Industry 4.0 digital automation solutions, in line to its objectives, see Figure 14.2 above:

- **Maximize Industry 4.0 RoI**, DSA services and DATV solutions will help optimize the SMEs investment for digital shopfloor implementation.
- **Keep integration time under control**, DSA-established methods and framework ease the adoption of digital solutions through validated deployments and access to certified testbeds.
- **Ensure future digital shopfloor extendibility**, relying on DATV-validated and standard-compliant components and DSA RA to safely plan the digital transformation strategy towards a future digital shopfloor.

On the business dimension, the DSA ecosystem is offering **a set of services to support SMEs in defining and executing their own digital transformation strategy** (see Figure 14.3), including:

Figure 14.3 DSA ecosystem strategic services.

- **DSA profiling**; DSA experts offer SMEs support on digital shopfloor profile selection, and ROI assessment of their digital shopfloor strategy.
- **DSA certification**; DATV framework application ensures safe operation of customised DSA deployments in modular/reconfigurable manufacturing cell or collaborative robotic workplace.
- **DSA integration**; DSA network of expert integrators offers suitable support for the safe and secure deployment of the digital shopfloor services.
- **DSA-ready products**; DATV HW components and SW solutions and infrastructures validated for purpose (VPP) helps reduce the ramp-up time of digital shopfloor services.

This set of services oriented to manage and support the digital transformation strategy for manufacturing SMEs' shopfloors is based on the AUTOWARE technical usability and V&V enablers and exploitable results. The DSA digitisation strategy's first steps will comprise a **digital transformation status assessment** that will enable the **digital transformation strategy and an action plan definition** through an **investment proposal aligned with the manufacturing SME global strategy and situation**, ensuring future extendibility of the deployments in the shopfloor and maximizing the Industry 4.0 ROI. The next steps will be supported by both catalogue of the DATV Core Products and validated deployments for specific purposes and

Figure 14.4 DSA-aligned open HW & SW platforms.

the Integrators network services, eased by the access to trial-ready testbeds in neutral facilities offered by the Autoware partners and manufacturing DIHs.
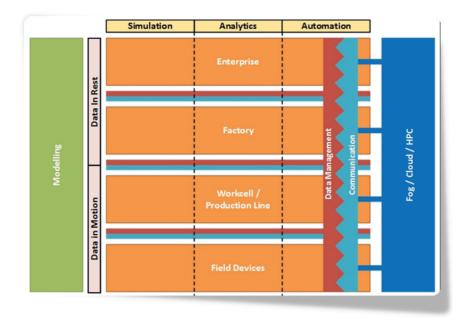
On the technological dimension, the DSA is centred in the AUTOWARE-based RA and aligned with main open HW and SW Platforms groups and initiatives in the digital automation area for Industry 4.0, as can be seen in Figure 14.4.

DSA catalogue of Core Products (DSA-CP) will offer, thanks to DATV certification framework, a complete description including the classification of the different DSA technology levels (visualization, security, connectivity, and open standards) achieved by the DSA-CP, its set of components, main features, DSA-RA mapping, component providers, qualified integrators availability (training level backed by CP owner, own homologation and expertise), estimated investment cost & deployment time table depending on complexity level of deployment.

14.4 DSA Reference Architecture

The RA aligned AUTOWARE manufacturing technical enablers, i.e. robotic systems, smart machines, cloudified control, secure cloud-based planning systems, and application platforms to provide cognitive automation systems as solutions while exploiting cloud technologies and smart machines as a common system. The AUTOWARE RA goal is to have a broad industrial applicability, map applicable technologies to different areas and guide technology and standard development.

The AUTOWARE RA has four levels, which target all relevant layers for the modeling of CPPS automation solutions (as depicted in Figure 14.5):

Figure 14.5   AUTOWARE Reference Architecture (layers, communication, & modelling).

Enterprise, Factory, Workcell, and Field devices. To uphold the concept of Industry 4.0 and move from the old-fashioned automation pyramid, the communication pillar enables direct communication between the different layers by using Fog/Cloud concepts. Finally, the last part of the RA focuses on the actual modelling of the different technical components inside the different layers. Additionally, to maintain compliancy with the overall AUTOWARE Framework, the reference architecture of the Software Defined Autonomous Service Platform (SDA-SP) broadens the overall AUTOWARE RA (see Figure 14.6) with the mapping of main technologies and CPPS services identified:

- A reconfigurable workcell that demonstrates solutions typical for robot automation tasks, e.g. robotic assembly using multiple robots;
- A mixed or dual reality supported automation to illustrate an automation solution that builds upon and benefits from intensive use of technologies like Virtual Reality (VR), Augmented Reality (AR), and Augmented Virtuality (AV). This system will be used to demonstrate the application of these technologies for automatic assembly of custom-ordered pneumatic cylinders.
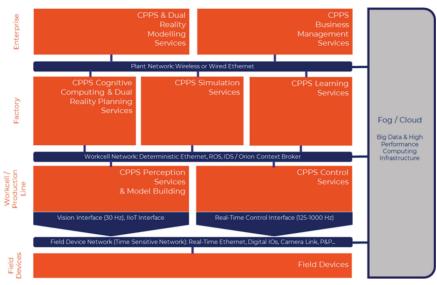
Figure 14.6   AUTOWARE Reference Architecture (SDA-SP).

- A multi-stage production line, where configuration, production, and traceability is built upon use of digital product memory technologies and functionalities.

Table 14.1 presents a list of AUTOWARE enablers mapped with the AUTOWARE-based RA different layers, network levels, and dimensions identified in Figure 14.6.

14.5 AUTOWARE Certification Usability Enabler

AUTOWARE will improve the European manufacturing industry situation by opening the door to new digital and digitally modified business opportunities with immediate global reach. Moreover, it will provide the enablers for putting innovation faster in the market with better streamlined customer processes and customer insights. The adoption of the CPPS technologies by SMEs is a well-known issue in which AUTOWARE has a major role in the automatization process by SMEs, facilitating that the SMEs build more sustainable and innovative business models. In addition, it also allows SMEs to focus both on the development or exploitation of the personalized applications and on the services to operate their strategic business assets (brand, culture, distribution, sales, production, and innovation).

Table 14.1 AUTOWARE enablers aligned to DSA-RA

AUTOWARE Enablers	Enterprise Services	Factory Network	Factory Services	Workcell Network	Workcell Services	Field Device Network	Field Devices	OpenFog & Cloud dimension, BigData & HPC	Ecosystem (Innovation, validation & standardization)
Validation & Certification usability enabler									x
FIWARE for Industry usability enabler		x		x				x	
Smart data distribution mechanisms		x		x		x			
Development of a gripping concept					x		x		
Development of a safety concept for the collaborative workplace					x				
Active Digital Object Memories (ADOMe)					x				
Neutral experience facility – Automation processes	x	x	x	x	x	x	x	x	x
Deep learning & high performance computing for reconfigurable robotic workcells			x		x			x	
Efficient robot tasks deployment using novel programming by demonstration framework			x		x				
OpenFog Architecture		x		x		x		x	
Human-Robot Collaborative Workplace	x		x		x		x		x
Faster (re-)training of vision systems based on deep neural networks					x		x		
Hierarchical Communication and Data Management Architecture for Industry 4.0		x		x		x			
Scalable & Self-Organizing Industrial Wireless Networks		x		x		x			
Deterministic industrial 5G communications		x		x		x			
Reliable industrial wireless communication						x			
Mobile robotic pilot for intra-logistic operations						x			

The impact on traditional SMEs, as shown in Figure 14.7, is immediate since technological complexity is decoupled from business value and a simple path towards maximizing the business value of advanced CPPS is facilitated. AUTOWARE hides the complexity of automatization to allow Future Internet SMEs and entrepreneurs to devote their resources and energies to effective and efficient business operation and value generation.

The number of technologies and platforms that need to be integrated to realize a cognitive automation service for Industry 4.0 is significantly high and complex. To this end, the AUTOWARE-proposed RA is rooted on solid foundations and intensive large-scale piloting of technologies for the development of cognitive digital manufacturing in autonomous and collaborative

Figure 14.7 AUTOWARE business impact on SMEs.

robotics as an extension of ROS and ReconCell frameworks and for modular manufacturing solutions based on the RAMI 4.0 Industry 4.0 architecture.

The digital convergence of the traditional industries is increasingly leading towards the disappearance of the boundaries between the industrial and service sectors. In March 2015, Acatech [9], through the Industry-Science Research Alliance's strategic initiative "Web-based Services for Businesses," proposed a layered architecture to facilitate a shift from product-centric to user-centric business models. At a technical level, these new forms of cooperation and collaboration will be enabled by new digital infrastructures.

Smart spaces are the smart environments, where smart, internet-enabled objects, devices and machines (smart products) connect to each other. The term "smart products" not only refers to actual production machines but also encompasses their virtual representations (CPS digital twins). These products are described as "smart" because they know their own manufacturing and usage history and are able to act autonomously. Data generated on the networked physical platforms is consolidated and processed on software-defined platforms. Providers connect to each other via these service platforms to form digital ecosystems. AUTOWARE extends those elements, which are critical for the implementation of the autonomy and cognitive features. AUTOWARE also extends those reference models adopting the layered structure suggested by the Industry 4.0 Smart Service Welt initiative [10] (shown in Figure 14.8) for digital business ecosystem development based on industrial platforms (smart product, smart data and smart service).

AUTOWARE at the smart product level leverages enablers for deterministic wireless CPPS connectivity (OPC-UA and Fog-enabled analytics). At the smart data level, the AUTOWARE technical approach is to develop cognitive planning and control capabilities supported by cloud tools
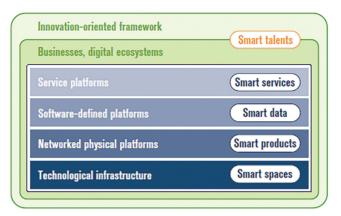
Figure 14.8   Smart service welt data-centric reference architecture.

and services and dedicated data management systems that will contribute to meet the real-time visibility and timing constrains of the cloudified planning and control algorithms for autonomous production services. Moreover, at the smart service level, AUTOWARE provides secure CPS capability exposure and trusted CPPS system modeling, design, and (self) configuration. In this latter aspect, the incorporation of the TAPPS CPS application framework, coupled with the provision of a smart automation service store, will pave the way towards an open service market for digital automation solutions which will be "cognitive by-design." The AUTOWARE cognitive operating system makes use of a combination of reliable M2M communications, human-robotics-interaction, modelling and simulation, and cloud and fog-based data analytics schemes. In addition, taking into account the mission-critical requirements, this combination is deployed in a secure and safe environment, which includes validation and certification processes in order to guarantee its correct operation. All of this should enable a reconfigurable manufacturing system that enhances business productivity.

14.5.1 AUTOWARE Certification Techniques

As previously stated, including validation and certification processes in AUTOWARE, Open CPPS ecosystem offers an easy adoption, secure environment, and greater credibility to SMEs. The planning and control of production systems has become increasingly complex regarding flexibility and productivity as well as regarding the decreasing predictability of processes. It is well accepted that every production system should pursue the following three main objectives:

- Providing capability for rapid responsiveness,
- Enhancement of product quality, and
- Production at low cost.

These requirements can be satisfied through highly stable and repeatable processes. However, they can also be achieved by creating short response times to deviations in the production system, the production process, or the configuration of the product in coherence to overall performance targets. In order to obtain short response times, a high process transparency and the reliable provisioning of the required information to the point of need at the correct time and without human intervention is essential. As a result, variable and adaptable systems are needed resulting in complex, long, and expensive engineering processes.

Although CPPS are defined to correctly work under several environment conditions, in practice, it is enough if it properly works under specific conditions. In this context, certification processes help guarantee the correct operation under certain conditions making the engineering process easier, cheaper, and shorter for SMEs that want to include CPPS in their businesses.

In addition, certification can increase the credibility and visibility of CPPS, as it guarantees its correct operation even following specific standards. If a CPPS is certified to follow some international or European standards or regulation, it is not necessary to be certified in each country, so the integration complexity, cost, and duration highly reduce. Nowadays, security and privacy are one of the major concerns for every business. SMEs with no specific knowledge need to be able to quickly assess, if an item provides confidence that required security and privacy is provided. For example, a minimal required barrier may need to be set to deter, detect, and respond to distribution and use of insecure interconnected items throughout Europe and beyond.

Security certification as a means of security assurance demonstrates conformance to a security claim for an item and eases the adoption of CPPS. Many certification schemes exist, each having a different focus (product, systems, solutions, services, and organizations) and many assessment methodologies also exist (checklists and asset-based vulnerability assessment). Some of the most important standards related to security are as follows:

- **ISO 10218-1:2011:** It is the standard that specifies the requirements and guidelines for the inherent safe design, protective measures, and information for use of industrial robots. It describes the basic hazards

associated with robots and provides requirements to eliminate, or adequately reduce, the risks associated with these hazards. It does not address the robot as a complete machine. Noise emission is generally not considered a significant hazard of the robot alone, and consequently noise is excluded from the scope of ISO 10218-1:2011.

- **ISO 10218-2:2011:** It is the standard that specifies safety requirements for the integration of industrial robots and industrial robot systems as defined in ISO 10218-1, and industrial robot cell(s). The integration includes the following:

    ○ the design, manufacturing, installation, operation, maintenance and decommissioning of the industrial robot system or cell;
    ○ necessary information for the design, manufacturing, installation, operation, maintenance and decommissioning of the industrial robot system or cell; and
    ○ component devices of the industrial robot system or cell.

ISO 10218-2:2011 describes the basic hazards and hazardous situations identified with these systems and provides requirements to eliminate or adequately reduce the risks associated with these hazards. ISO 10218-2:2011 also specifies requirements for the industrial robot system as part of an integrated manufacturing system.

- **ISO/TS 15066:2016:** It is the standard that specifies the safety requirements for collaborative industrial robot systems and the work environment and supplements the requirements and guidance on a collaborative industrial robot operation given in ISO 10218-1 and ISO 10218-2.

Various methods can be used to systematically test and improve the security of CPPS systems. Apart from testing individual software components for security-related errors, all components of the CPPS infrastructure can also be tested, and the associated processes can be systematically examined and improved.

Depending on the initial situation, technical security tests may start at various testing stages, from all phases of the engineering or development cycle to integration testing and acceptance of the production infrastructure. It is possible to identify and eliminate security faults and the resulting risks at an early stage for relatively little cost, saving money, improving the accuracy of the planning and staying one step ahead of potential hackers.

Figure 14.9 Main characteristics of CPPS solutions that are desired by SMEs.

Summarizing, it is well known that SMEs choose CPPS solutions that assure a correct operation, are easy and cheap to adapt, as well as safe & secure (see Figure 14.9). In addition, the CPPS solutions have greater credibility if they are made with certified tools, guaranteeing their correct operation under specific conditions defined according to the specific application requirements. Moreover, certification increases the solution visibility and makes the maintenance operation easier.

14.5.2 N-axis Certification Schema

Once the AUTOWARE solution is finished, a certification process is needed in order to guarantee the solution's correct operation and assure its compliance with the regulation. As a result, the engineering, integration, and launching processes are easier, cheaper, and shorter for SMEs. The AUTOWARE-proposed certification methodology consists of the following different stages.

14.5.2.1 Data collection

In this step, all the data useful for the certification process is collected. For example, documentation, which are the components, which technologies are used, what risks exist, etc. In the case of the components, it is also necessary to determine if they are critical, security, technological or commercial components, and if they are already certified or not. Table 14.2 shows an example of a possible template for obtaining data related to the solution/production. This information can be directly provided by the client or obtained by the certifying team during an ocular review.

Different options can be considered for the data collection, such as customer surveys, product/solution inspection, interviews, videos, etc. All of them are compatible and complementary to each other and their results can be combined.

Table 14.2   Data collection template for the certification process

	Component 1	Component 2	Component 3				Component n
Critical							
Certificate							
Security Level							
Technology							
Commercial							

14.5.2.2 Strategy

An appropriate strategy must be determined depending on the specific product/solution and the data obtained during the data collection process. For this purpose, the following questions must to be answered.

- Which tools are the most appropriate?
- How far the certification process has to go?
- What type of tests should be defined?

Depending on the data obtained in the data collection process, an appropriate series of tests must be defined encompassing as much as possible all the different possibilities: functional tests per component, integrity tests, unit tests per component, complete functional tests, etc.

14.5.2.3 Test execution

During this phase, the different tests defined during the strategy process are executed using the selected tools.

14.5.2.4 Analysis & reports

The results obtained from the test execution process are analysed in order to detect possible errors and indicate the level of criticality. The results obtained from the data analysis are gathered in a relevant report for the customer.

This four-phase process applied to the different system components and considering the different kind of components has to be combined with different fields of action (medicine, aviation, etc.) and with different standards (ISO-15066, ISO10218-1, ISO-10218-2). For this reason, the AUTOWARE certification scheme must be a multi-axis certification scheme such as that shown in Figure 14.10.
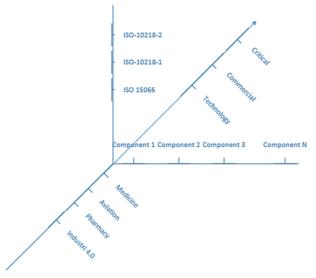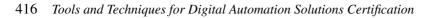
Figure 14.10   Multi-axis certification solution.

14.6 DSA Certification Framework

DSA RA compliant components provided by large well-known providers of technologies are the base for the development of Core Products designed and validated for a purpose (previously defined as predictive maintenance, zero-defect manufacturing, energyefficient manufacturing, etc.). Each **DSA Core Product** (as shown in Figure 14.11) should be composed by a set of DSA RA-compliant components with their matching datasheets (features and performance specifications), configuration & programming profiles and validation for purpose profiles (VPP), **as guidance to ensure DATV** when integrated in future solutions. Thanks to the support and training offered by Core Product owners, **Medium & Small Integrators** within the DSA network of experts will offer their services for the implementation of a **validated deployment** with customized Core Products for the specific application demanded by the manufacturing SMEs.

AUTOWARE promotes the use of open protocols & standards such as HW platform (openFog), connectivity (MQTT, TSN, iROS), control (IEC61499) data protocol (OPC-UA), data sharing (IDS, FIWARE/ETSI Context Information Framework), and data security. Individual components should support relevant open standards, APIs and specifications to become part of the AUTOWARE framework. However, AUTOWARE does not promote the simple certification of individual components but moreover the
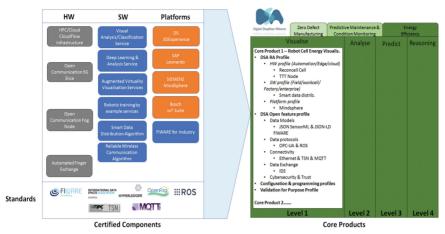
Figure 14.11   DSA-integrated approach for Digital Automation Solutions Certification.
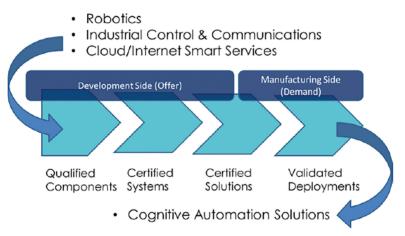

Figure 14.12   Digital automation solutions certification workflow.

availability of **core products** (HW infrastructure and software services and digital platforms) that are **constructed following the DSA RA architecture**; built **for a purpose** (visualisation, analysis, prediction, reasoning) **in the context of specific digital services** (energy efficiency, zero defect manufacturing, and predictive maintenance) **for manufacturing lines** (collaborative workspaces, robots, reconfigurable cells, modular manufacturing), as can be seen in Figure 14.12.
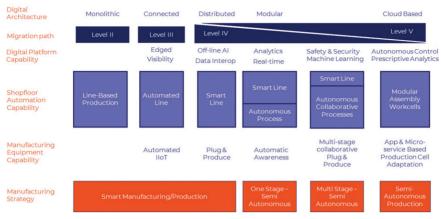
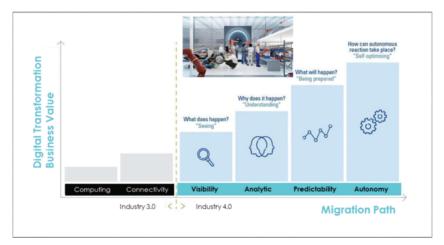**Figure 14.13** DSA capability development framework.

Figure 14.14 DSA service deployment path.

The DSA approach, based on the access to DATV Core Products and Solutions and DSA expert professionals and services, will reduce considerably the integration and customization costs of validated deployments. Through the proposed certification framework and DATV tools, the DSA aims to maximize the Industry 4.0 ROI and ensure the future scalability/extendibility of the digital shopfloors, by the implementation of a capability development framework (shown in Figure 14.13) and a service deployment path (shown in Figure 14.14) that guide SMEs in their Digital Transformation strategy in order to leverage their automation solutions visibility, analytic, predictability and autonomy.

After a preliminary vision in joint exploitation description of some of the main DSA Ecosystem Players (i.e. providers of the DSA products and services, medium & small integrators...), a detailed mapping of the **DSA ecosystem players** and their roles and strategies in the DSA ecosystem, based in a win-win model, is presented here:

- **Open HW and Open Platform initiatives and groups** will provide the required support for the established DSA RA and open source Industry 4.0 technologies. They will join the DSA Ecosystem as members by signing a Memorandum of Understanding, MoU, where their contributions will be defined. DSA will support the interaction of the rest of the ecosystem players like integrators to ease the adoption of these technologies and the certifications associated with the open technologies. This category could integrate interested universities and research centres working on these open technologies.

- **Manufacturing Champions**, the key Large Manufacturing Companies will have an essential role in the DSA as main tractors of the manufacturing sector, since they define the regulations and standardizations required to their providers' network. DSA ecosystem will study and analyse the sector demands and needs to ensure the Manufacturing Champions endorsement align their activities in the right direction. As DSA members, Manufacturing Champions pay a fee that will allow them access to a DSA-validated network of homologated providers implementing DATV deployments that ensure safe operation, energy efficiency, and quality performance first contacts with the main manufacturing companies will be done for instance through the Boost 4.0 Lighthouse European project.

- **Technology Providers**, the main technology providers (i.e. Siemens, Bosch, ATOS) will join the DSA Ecosystem as Core Product owners offering these DATV solutions ready to be customized and integrated in the shopfloor, associated maintenance, and support & training services. Prior to join DSA, technology providers' components and Core Product should be DSA open SW, open HW and open Platform compliant, providing associated datasheet, configuration & programming profiles and validation for purpose profile. As DSA members, the Technology Providers will pay a fee that provide them an alternative access to SME manufacturing companies market, not profitable for the direct sale of their SW packages, platforms and services. The Technology Providers will be able to offer adjusted prices to developers and thus access this SME market.

- **Development Partners** will form a network of small and medium integrators, qualified for the implementation of validated deployments for customized solutions for manufacturing SMEs. DSA will search a first contact with the Digital SME Alliance to have access to potential development partners. Prior to joining the DSA network of experts, these small and medium integrators should comply with specific training on the Core Products and DSA technologies, architecture and strategy, and provide a signed SLA. The DSA network provide an homologation methodology based on the training levels on the different DSA technologies and their expertise that, together with a cost/time estimation table for different deployment complexities, will give them visibility and a way to improve their competitive position.
- **Manufacturing SMEs**, DSA offers them not only the services and technologies for digital transformation and implementation of Digital Shopfloor technologies, but the visibility as DSA homologated providers to large manufacturing companies. Manufacturing SMEs main access to DSA will be not only the DSA platform/ecosystem web, but through the activities and services offered in clusters and DIH focused on manufacturing sector, and other agents like the Trilateral Alliance cooperation between German Plattform Industrie 4.0, French Alliance Industrie du Futur and Italian initiative Piano Industria 4.0, or Spanish Industria Conectada 4.0.

DSA will also work for the **integration of standardization methodologies** in DSA solutions and deployments, considering not only the technological aspects but other aspects like data protection and GDPR.

As a summary Table 14.3 is presented with the initial players identified in DSA ecosystem within AUTOWARE project, and the potential players that will conform the DSA ecosystem in a future.

14.7 DSA Certification Methodology

The DSA intends to promote the appropriate ecosystem to develop and commercialize Innovative Solutions that respond and can be adapted to end-user needs. When defining the mission pursued by the DSA, a reflection has been made on the key aspects when starting an initiative of this kind:

- WHY: A different way to commercialize I4.0 solutions; Implement DT to Industry; Foster the creation of innovative products

Table 14.3 Identification of DSA players

DSA Players	Preliminary Stage (AUTOWARE)	Future Stages (DSA Potential Players)
Open HW and Open Platform initiatives and groups	UMH, CNR, Fraunhofer, imec, INNO (open initiatives alignment role)	FIWARE, IDS, openFog, iROS, OPC-UA…OpenForum Europe
Manufacturing Champions	Fraunhofer, INNO, Blue Ocean, SQS (manufacturing sector alignment role)	Key manufacturing large companies from different sectors (i.e. Boost4.0 champions) National Manufacturing Enterprise Associations (CONFINDUSTRIA, It's OWL, FrenchTech…)
Technology Providers	TTTech, JSI, Robovision	EIT Digital, AIOTI Siemens, Bosch, SAP, Huawei, Telefonica, Azzure, CloudFlow, Dassault, ESI Group…Digital SME Alliance
Development Partners	SmartFactoryKL, JSI, Tekniker (Neutral Experimental Facilities as integrators)	Digital SME Alliance for Small & Medium IT Integrators…
Manufacturing SMEs	SMC, Stora Enso (industrial Use Cases)	Sectorial clusters & DIH, German Plattform Industrie 4.0, French Alliance Industrie du Futur, Italian initiative Piano Industria 4.0, Spanish AIC…

- HOW: Offering solutions vs technologies; creating an ecosystem of beneficiaries from stakeholders from research to end-users;
- WHAT: Consultancy; Certification; Solutions; Integration

This analysis has led us to the definition of four key sets of services to be offered within DSA ecosystem: Consultancy, Certification, Integration, and Solutions as shown in Figure 14.15, with the support of the certification framework that ensures easy configuration and operation of reliable scalable open based Digital Automation Solutions with low cost and fast RoI deployment. As shown in Figure 14.16, DSA certification methodology covers the Core Product key aspects to successfully support a manufacturing SME in its digital transformation strategy:

- FUNCTION: Identified key functionality aspects, defining processes and customisation, global, interoperability, and standard features of the core product

CONSULTANCY
1

To help design and implement a Roadmap for I4.0

CERTIFICATION
2

Offer Validation of Core Products & Installations

INTEGRATION
3

Offer Local Integrators to adapt a generic product to meet customer needs

SOLUTIONS
4

Generic Products to implement a Function

Figure 14.15   DSA key services.

Function; Customizable; Global; Interoperable; Standards

Open SW/HW components; Reference Architecture; Validated; Configuration Utilities

Network of Local Experts; Fixed Price + Variable; Operations & Support

Figure 14.16   DSA key services.

- TECHNOLOGY: Identified open SW/HW components, RA alignment, validation, and configuration tools
- DELIVERY: Identified network of local experts for integration & training, pricing model, and operations & support services

Moreover, the integration of diverse stakeholders in the DSA ecosystem fosters the adoption of I4.0 & leverages the creation of innovative products:

- TECHNOLOGY PROVIDERS: Provide core components and technologies, Open HW and Open Platform Initiatives and Groups, and Research & Private
- SOLUTION PROVIDERS: Core products/solution developers
- INTEGRATORS: Adapt core products to end-user needs
- VALIDATORS & CERTIFIERS: Validate core products/solutions and their adaptations Service Providers V&V
- STANDARDIZATION BODIES: Technology and process related
- MANUFACTURING: Large (Prescription & Customers), SMEs (end-users/Customers), Clusters (Prescription), and Industrial Associations (Prescription)
- CONSULTANCY: Digital transformation consultancy experts.

14.8 Conclusion

This section has presented the foundation of the DSA and the associated validation and verification framework as the basis to develop a manufacturing driven multi-sided ecosystem. The DSA is originated as a means for SMEs to navigate and exploit the large set of tools and platforms available for the development of digital solutions for the digital shopfloor. This paper has discussed how the DSA approach can nurture synergies across multiple stakeholders for the benefit of SME digitization and the gradual integration of the digital abilities in the digital shopfloor with a business impact. This paper has presented main standardization and compliance drivers, for instance, digital shopfloor safety in advanced robotic systems as one of the multipliers for adoption and the need for a DSA ecosystem that facilitates navigation across standards, platforms, and services with a focus on business competitiveness. This paper has also presented the fundamental services envisioned for such DSA and the dimensions that need to be validated to ensure that digital abilities such as automatic awareness can be fully realized in the context of cognitive manufacturing digital transformation.

Acknowledgments

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