Global Industry Standards for Industrial IoT

An Industrial Internet Consortium White Paper

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The Industrial Internet of Things (IIoT) is a rapidly expanding world of connected objects. As IIoT systems proliferate, large amounts of data are consumed by machine learning algorithms and shared between partners, customers and others. IIoT is a technology environment in which integration and interoperability are critical capabilities and the complexity of this environment makes this difficult to achieve. Standards play a critical role in IIoT for five main reasons.

First, users and vendors cannot engineer a custom interface every time components or systems need to interact. Standards can make this explosion of interfaces manageable; they are the *lingua franca* for interoperability. For suppliers, this eliminates needless costs related to common capabilities instead encouraging a focus on innovations that add value.

Second, Information Technology (IT) and Operational Technology (OT) need to work together to achieve digital transformation of the enterprise, and this implies that OT can no longer deploy isolated islands of automation, often comprising equipment from a few vendors, that do not conform to the protocols or data formats used elsewhere. To achieve the benefits of IIoT, those environments are now connected to enterprise systems and to each other through the internet, and must therefore adhere to IT communication, security and data norms.

Third, customers are requiring standards compliance to avoid vendor lock-in. This creates a competitive environment in which failure to support standards—international, regional, industry-specific or function-specific—becomes a competitive disadvantage. Conversely, active involvement projects a supplier's thought leadership and increases customer confidence.

Fourth, regulatory agencies respond to the need for safety, security, and reporting by requiring adherence to standards to make their monitoring and auditing work feasible.

Fifth, standards make employee skills portable across divisions and companies, which benefits both the workforce and the companies that employ them by flattening the learning curve.

Organizations (such as IIC members) must respond to these imperatives by defining a standards strategy and taking certain actions to execute it. The strategy could be simply to adopt and implement standards as they emerge, but this limited engagement exposes the organization to surprises. Participating in standards development organizations (SDOs) provides greater control and allows an organization to anticipate the emergence of new standards. This requires a commitment at all levels and affects the organization, its processes, product design and budget.

This document examines the above in detail. It enumerates categories of standards and the organizations that produce them. It establishes a vision and strategy to drive and leverage standards. Also, it provides concrete guidance to the industry on execution and governance. In short, this document fulfills Industrial Internet Consortium's (IIC's) goals of recommending classes of standards to the members, influencing standards development in the interest of our community, and demonstrating the value of standards by deploying them in our testbeds. We

encourage IIC members to apply this guidance in the development, adoption and use of IIoT standards, enabling interoperability and system compatibility across the whole IIoT ecosystem.

1 STANDARDS DEVELOPMENT ORGANIZATIONS AND INDUSTRY CONSORTIA

This section describes the landscape of SDOs, industry consortia and associations involved in the development and adoption of standards. We have produced a catalog of such organizations relevant to the IoT domain. This catalog appears in Appendix A. Note that any static catalog of this kind is liable to become obsolete quickly, as the list can be neither permanent nor exhaustive.

Figure 1-1 depicts the types of organizations, placing them along a horizontal axis corresponding to the phases of a standards lifecycle.

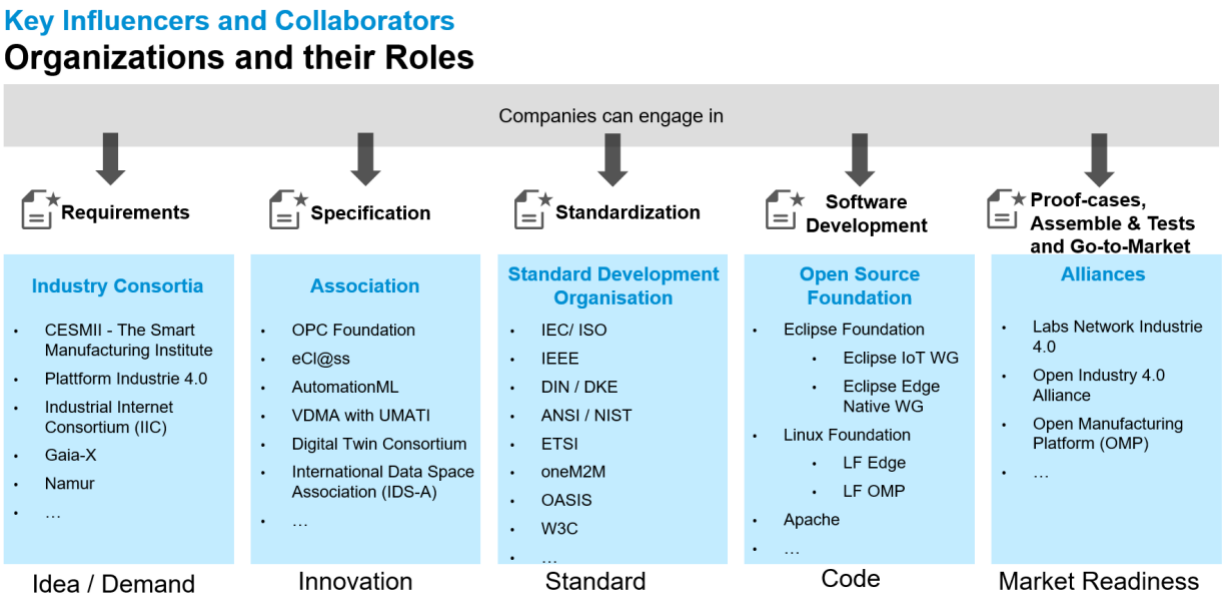

Figure 1-1: Organization Types and Their Standards Lifecycles

1.1 STANDARDS DEVELOPMENT ORGANIZATIONS

Standards development organizations, by definition, develop and publish standards.

A standard is a repeatable, harmonized, agreed and documented way of doing something, and is generally established by an accredited institution.

Some SDOs have been established by national or international authorities and are recognized as authoritative by them. The best-known example of those is probably the International Organization for Standards (ISO). An extensive market of commercial companies that provide training and compliance certification is usually associated with those standards.

SDOs tend have defined processes to work together. For example:

- the adoption of an ISO standard requires reviews and votes by the SDOs of member countries (e.g., American National Standards Institute [ANSI] for the United States, Deutsches Institut für Normung [DIN] for Germany, Association Française de Normalisation [AFNOR] for France).
- Object Management Group (OMG), the parent organization of the IIC, has an agreement with ISO that allows an OMG adopted specification to be submitted to ISO as a "publicly available specification" (PAS), often resulting in faster adoption as an ISO standard.

1.2 INDUSTRY CONSORTIA AND ASSOCIATIONS

A *consortium* (plural: consortia) "is an association of two or more individuals, companies, organizations or governments (or any combination of these entities) with the objective of participating in a common activity or pooling their resources for achieving a common goal."[1, 2]

The IIC is such a consortium; so is its sister program, the Digital Twin Consortium (DTC). IIC member companies have assembled to find solutions for the next industrial revolution, mainly to identify and document the requirements for new technologies and new business models.

Many consortia, such as IIC, do not develop standards themselves; however, they often advocate for them. When the need for a standard emerges out of the members' collaboration, the consortium will either identify an existing suitable standard, or will approach an SDO (with a process detailed in the next section) to encourage the development of a new standard. The consortium members then become some of the subject matter experts who can help the SDO define the requirements for the standard and test it once it is developed.

Consortia and industry associations can have a number of goals:

- Some exist to share knowledge and provide networking opportunities to their members (e.g., periodic industry conferences).
- Others are formed to influence policy–that is, to lobby governments to adopt or reject policies and regulations to maximize the industry's freedom of action (and profits). This is usually done at the regional level, matching the structure of each government.
- Some exist to facilitate the development of shared technology, which nowadays may take the form of an open source project.
- Finally, some consortia and associations create specifications that, without having the force of a standard from an SDO or consortium, are voluntarily adopted by a plurality of the association's members, thus becoming a *de facto* standard.

[1] *https://www.irena.org/inspire/Standards/What-are-Standards*
[2] *https://en.wikipedia.org/wiki/Consortium*

2 CATEGORIES OF STANDARDS

External standards comprise four main categories: open, closed, *de jure* and *de facto*.

An o*pen standard*:[3]

- offers everyone the ability to participate in the development of a standard without barriers to entry, either without cost or for a nominal administration fee,
- offers everyone the ability to obtain the published version of a document, either without cost or for a nominal fee and
- places no or few restrictions on their use.

Open standards are publicly available and have various rights-to-use associated with them, and the authoring process used to develop open standards can vary widely. There is no single definition for an "open standard" and interpretations vary with usage.

Open standards are generally developed in public settings with open membership, allowing all interested stakeholders to participate under well-publicized bylaws, contribution policies and deliverable licensing terms such as royalty free (RF) or Reasonable and Non-Discriminatory (RAND) terms. This approach is crafted to ensure vendor neutrality in open standards.

Closed standards can be developed and licensed by a handful of companies or even individuals. Input from the broader user community is generally not accepted. Closed standards often have restrictive licensing requirements in terms of permitted use (restricted to members only, for example) or costs to obtain and use the standard.

A *de jure* standard is a technology, method or product that has been officially endorsed in law.

De jure, from medieval Latin, means *from law*. The term refers to legally protected or enforced standards and to those that have been endorsed by an official standards organization, such as ANSI or Internet Engineering Task Force (IETF).

Examples of *de jure* standards include:

- American Standard Code for Information Interchange (ASCII), the most common format for *English text file*s in computers and on the internet,
- Small Computer System Interface (SCSI), a set of ANSI standard electronic interfaces that allow personal computers to communicate with peripheral hardware, and
- Transmission Control Protocol/Internet Protocol (TCP/IP) is the IETF-endorsed standard communication language or protocol of the Internet.

[3] *https://en.wikipedia.org/wiki/Open_standard*

De facto standards can be open standards, closed standards or deliverables from organizations or individuals whose primary purpose is other than standards setting but who deliver methodologies that equate to standards through either public acceptance or their licensing agreements. De facto standards may or may not be called standards, but they can carry the same weight as an official de jure standard. Some examples of de facto standards are:

- methodology books by noted authors,
- methodology documents from requirements organizations such as Plattform Industrie 4.0 and its RAMI 4.0 and the IIC and its Architecture, Connectivity, Industrial Analytics and Security Frameworks,
- methodology documents delivered from open source projects such as those from the Linux Foundation or Eclipse Foundation, to support open source offerings,
- required processes published by government agencies such as the United States Federal Information Processing Standards and
- the ".doc" and ".docx" formats for storing document content as specified by Microsoft.

3 DEFINING A STANDARDS STRATEGY

The purpose of this section is to allow enterprises to consider the range of strategies they might adopt with respect to standards, based on a clear understanding of the advantages and risks posed by those strategies with respect to their product roadmap and in particular their intellectual property portfolio. We then review how the selected strategy can be implemented, and in particular how a company may decide to contribute actively to standards efforts rather than simply waiting for others to define them.

While the proposed standards strategy was primarily developed from the perspective of IIoT technology or solution suppliers, as evidenced by the references to intellectual property protection and product lifecycle, organizations that are buyers and users of IIoT will find that much of this section applies to defining their own strategy as well. We conclude this section by outlining the ways in which the strategy elements below can be adapted to the case of end users.

3.1 INTELLECTUAL PROPERTY (IP) VS. STANDARDS

Adoption of standards over time: It is common for technologies, in their early years, to have a tense relationship with standards:

- During the emerging phase, where technology development is led by research groups or by startups, standards are not seen as important or may even be considered harmful to innovation.
- During early commercialization, each supplier is keen to create and preserve an advantage, and to attract customers and lock them in to their proprietary technology.

- When the technology matures, customers discover the need for integration, interoperability, and migration from one system to another. At the same time, suppliers need to attract a broader clientele, and the need for standards emerges. At the end of this phase, *ad hoc* standards are defined but are not yet well adopted.
- When it becomes clear that more formality and governance are needed, the industry joins forces with standards organizations and initiatives. Compliance with standards becomes a selling point and a procurement criterion.

Premature standardization could stifle innovation, but delayed standardization creates unnecessary interchange, interoperability and integration difficulties. Today, many technology suppliers are still in the first or second stage above. They have not recognized the need for standards, or they are not yet convinced that adopting standards is in their best interest.

Commodity vs. innovation: An organization's IoT products are typically architected into a number of layers. The base layers are usually commodity components: hardware, operating systems or programmable logic, or communication protocols. The top layers provide the product's added value and contain proprietary features that distinguish the product from its competitors. Some of the intermediate layers, which may be homegrown or open-source software, may provide integration or interoperability with other products.

The choice of mature, standard-compliant components or interfaces for the lower and intermediate layers ensures that:

- components can be replaced by others that are "plug-and-play compatible" with the previous ones,
- market forces result in the best possible price for a given set of features,
- developers do not have to learn a different proprietary design as they move across companies and products and
- the different parts of a system can readily interoperate or communicate with each other, for example by sending data in a readily recognized format.

At the upper end of the technology stack, a company that wants to command a premium in the market is adding innovative features that give the product a competitive advantage. This can be in terms of advanced capabilities added through the incorporation of novel technologies such as machine learning or blockchain, but also more commonly through better performance, size, weight, user interface, programmability, etc., even aesthetics—aspects in which there is no standard and a superior product will likely be preferred by customers.

A product standard strategy primarily consists of product marketing and engineering rules and best practices to decide:

- what parts of an IoT product should be commodity components,

- what parts should be the focus of value-adding, proprietary innovation (and why) and how they should be protected (trade secret, patent or copyright),
- what parts should adhere to established standards, because there is no added value in creating or using a non-standard feature,
- where the absence of a standard is an obstacle and the organizations should take an active role in developing one and
- in that last case, which internally developed components can be contributed to the relevant community, and when they should be contributed to generate maximum value.

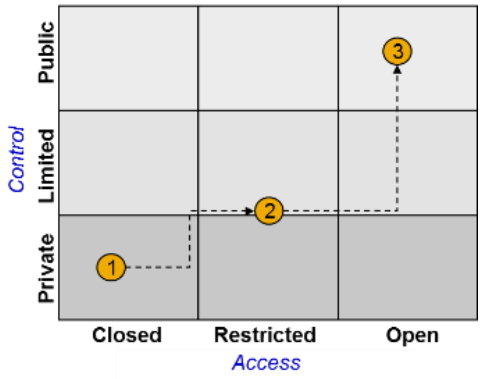

Figure 3-1: Standards Evolution Matrix with Development Stages

The standards matrix of Figure 3-1 describes the level of control a company may wish to maintain over their IP, the level of access the company may wish to grant to potential partners, standards bodies, or to the public, and how this positioning may evolve over time.

The figure illustrates a typical progression (but not the only possible one) in the development of a standard. It begins with a proprietary technology ① that originates with a single company, which controls its design and keeps it to itself. Over time, it is made available to a community of partners of users, who gain access without gaining control; it becomes a restricted, limited standard ②. As the degree of adoption increases, it then becomes advantageous to "donate" the technology to a consortium or international standards organizations, which increases adoption and enlists more resources in the development of the standard ③.

Note that there is the possibility of a reverse path in this matrix: companies sometimes "adopt and adapt" a standard, with the frequent consequence that the interoperability and portability benefits of the standard are lost (we saw this frequently in past decades with supplier-specific versions of programming languages or relational database architectures).

Open Source Considerations: Open-source artifacts are developed in a collaborative public manner and shared within a community under a license that grants rights to use, study, change, and share the product.

The various kinds of open artifacts include:

- Open standards comprise written documents. A licensing fee or special terms may be required to obtain and use them. Examples of open standards include standards issued by the World Wide Web Consortium (W3C), ISO, DIN, and IEC.
- Open source is code and data. It is typically available from a freely accessible repository (e.g., GitHub) or reference implementation and is usually licensed to end-users via a set

of open-source licenses. Open source gives you some measure of freedom to use the code and data as you need to, often without a license fee.

- Examples of open source include Apache Spark, OpenJDK, Linux OS and Linux Edge.
- Examples of open-source software licenses include the GNU Public License (GPL), Apache, Berkeley Software Distribution (BSD) and MIT license.

All are intellectual property of the contributor(s) and have contributing and use policies that have legal requirements. In many cases, reference implementations of standards become open-source projects in GitHub or elsewhere. Standards, just like open source, can ease development costs, help realize the connected enterprise and increase the attractiveness of solutions to customers.

3.2 RATIONALE FOR STANDARDS ADOPTION

There are several key reasons why adopting existing standards may be preferable to the use of legacy proprietary components:

- ensure interoperability with other suppliers' products, which makes the company's products more appealing to prospective customers,
- align the entire portfolio of products (including across multiple product lines), thus providing upselling opportunities,
- create demand for new products once enough vendors can interoperate,
- free up resources used to support non-standard components of a system,
- leverage the work of the open-source community,
- reduce the learning curve for new engineering and service personnel,
- benefit from evolution of the standard, ensured by multiple cooperating organizations,
- convince customers that their investment in the company's products is better protected than if they buy a non-standards-based product from a competitor and
- project an image of innovation and openness.

An example of how an IIC member company developed a technology and contributed it to the community, allowing it to become a standard that others could leverage, is OData, a standard protocol developed by Microsoft for creating and consuming RESTful Application Program Interfaces (REST API).[4] SAP (also member of IIC) and others joined Microsoft to further co-develop the OData specification, and later submitted them to OASIS to become a standard. Those companies successfully used an open technology strategy to maximize the value for themselves and their customers, creating developer mindshare around the standard and enhancing interoperability. OData was then implemented in both SAP and Microsoft products and deployed in open-source projects.

[4] *https://en.wikipedia.org/wiki/Open_Data_Protocol*

The adoption of standards is a consequence of the convergence between IT and OT. The custom hardware, software and network architectures of supervisory control and data acquisition (SCADA) systems are being replaced by off-the-shelf microprocessors, operating systems, and Internet protocols, which makes them cheaper and easier to integrate and manage. In turn, this requires adopting standard security and management protocols and practices, so that IT can ensure the safe coexistence of those resources with the rest of the corporate network as well as with cloud services. Over time, IT standards for distributed ledger technology and machine learning will also run at the edge.

3.3 DEFINING AN ENTERPRISE'S STANDARDS ENGAGEMENT STRATEGY

Companies must decide what their level of involvement should be. In other words, there must be a *business and technology strategy.*

In theory, a company can choose from a range of strategies. Some are better than others in a given situation – it depends on the nature of the product, the market it serves, the maturity of the industry, and other factors. The important thing is, a company must select one of those strategies with its eyes fully open.

First, there are three basic postures one finds in practice:

- *Ignore*: Let the designers choose the best fit-for-purpose technology based on product requirements. This may be appropriate when the product is going to have a short life span, or when there is no foreseen competition or need for integration, or when time and cost constraints can only be met by adapting a legacy proprietary product, rather than a new one that follows standards. This posture can lead to surprises and accidents during the development, sales or support phases.
- *Watch and adopt*: Observe (passively) the evolution of the technology and make *ad hoc* local decisions on what to use. This is appropriate when adherence to standards is necessary to be competitive or brings cost savings by decreasing the engineering and support effort, but influencing the development of standards is not worth the cost. The risk with this strategy is slipping into the complacency of the "ignore" strategy. The company may be taken by surprise by the emergence of a new standard or the evolution of an existing one, while a competitor with a more proactive engagement strategy is able to comply with the new or updated standard more quickly.
- *Engage*: The level of participation can vary, but at minimum it means becoming a member of some alliances, consortia or standards committees, helping review the direction of the work, and informing the product design community inside the company of the roadmap for future standards that may affect product plans.

If the company is even more ambitious, and has the appropriate experts on staff, it may take a leadership role, which includes actively communicating with other participants (including

competitors) about what the overall interests of the industry are, and how the standards should be shaped to achieve those benefits. This strategy can be costly: people who chair standards committees can find it to be a full-time job. And while this is an opportunity to align a standard with a company's technology choices, rather than the other way around, such a move is likely to be detected and resisted by competitors. This is the costliest posture, but it is the one that gives an organization the greatest ability to be a market leader, forcing the competition to play catch-up.

Other than the first option (ignore), each of the others require setting up the appropriate mechanisms and roles. We will see this when we discuss the execution of the strategy.

3.4 FORMS OF STANDARDS ENGAGEMENT

Engaging in standardization activities is part of an integrated strategic IP initiative. The stakeholders include the legal and marketing departments and must be supported at the Chief Executive Officer level to achieve one or more of the following goals:

- improve the product quality and customer experience,
- meet customer expectations for interoperability,
- reduce the development and support costs,
- accelerate the learning curve of new employees and
- demonstrate thought leadership.

Once these goals have been discussed, understood, and prioritized, one of the following common approaches can be selected:

- *Lead and migrate:* This is a common strategy with companies (or small groups of allied companies) that have developed a leading proprietary technology, such as a format a protocol, that has become a *de facto* standard: others already find that they need to offer some compatibility or interoperability with that standard. Once this leading position is established, its authors have the option to submit the specification to the appropriate SDO or consortium for standardization, resulting in wider industry adoption. Further evolution of the standard then becomes a shared effort between many organizations and can benefit from an open-source approach. Here are two examples of this approach that are particularly relevant to the IIoT domain:
    - Microsoft's proprietary Object Linking and Embedding (OLE), first released in 1990, was extended to provide a bridge between Windows applications and process control hardware, leading to OPC (OLE for Process Control) in 1996. The OPC Foundation was then created to maintain the standard. OPC was then adopted in various domains, resulted in its being renamed Open Platform Communications. It then underwent significant changes to become OPC Unified Architecture (OPC-UA). Released in 2006.

  - The Network Data Delivery Service (NDDS) was originally proposed by Stanford University and Real-Time Innovations (RTI) in 1994. It led to a joint development by RTI and Thales and the adoption of DDS (Data Distribution Service) by the OMG ten years later. Today, DDS software is produced by several companies and there is an OpenDDS open-source implementation.

- *Embrace and extend*: In this strategy, a company adopts an existing standard, but extends it within its own organization to meet its needs. The extensions can either be kept internally, at the risk of limited interoperability with other products that follow the original standard, or submitted back to the organization that owns the standard as input for future versions, similar to how code is contributed to an open-source software repository. Again, the decision to make the enhancements proprietary or to share them is strategic that involves more than technical staff.
- *Observe:* In this strategy, a company participates in standards development efforts to gather early information on what a standard will contain. This helps the engineering team to start "designing to the standard" before it is finalized, and it demonstrates involvement to customers, although no real contribution to the standard contents is intended. Attendance at committee meetings and e-mail exchanges allow networking with potential customers and partners, and intelligence gathering from competitors. The cost is limited, but while no direct contribution is made, there is still a risk of either exposing internal IP or other confidential information or infringing on someone else's IP as a result of this participation.
- *Neutralize:* This defensive strategy comprises participating in a standards development activity to prevent another company that dominates the market from imposing its technology as a standard. The "neutralizing" company typically wants to avoid the broad industry adoption of features they would not be able to support and does not want to appear as the loser in a battle of competing technologies. This means questioning, slowing down, or opposing any decisions by a standards committee that are biased to give the market leader an unfair advantage. This can be seen as obstructionist and requires much courage and diplomacy. The neutralize strategy can also be effective in conjunction with the "align and converge" strategy below.
- *Pilot:* Here, a company typically forms and leads an alliance that takes a newly defined standard and creates prototypes or testbeds to ensure that the standard is implementable. This is an important contribution, because the initial version of a standard may contain unclear elements or even some errors or impossibilities. At the same time, the participants end up with usable prototypes that can be evolved into actual products. Adjustments to the standard are fed back to the responsible organization, while the prototypes may or may not be shared with the rest of the industry or kept within the alliance, depending on the commercialization and IP strategy decided at the beginning.
- *Align and converge:* In this strategy, a company, typically a large and influential one (or a small group of companies) identifies multiple competing standards that they must

support, with the result that engaging separately and simultaneously with each SDO–including participating in meetings and contributing solutions–is too costly. The goal is to engage with the SDOs at the leadership level, garner consensus to align and combine their respective contributions, and find a single home for the converged standard.

3.5 Drivers of a Strategy Choice

When devising a standards strategy, consider the following:

- strategic opportunity or threat,
- business problems and value scenarios,
- corporate, technology and product strategy,
- IP value and licensing approach,
- product maturity,
- market share,
- the current standards landscape,
- the known standards activities of competitors,
- current customer or field service pain points (attributable to lack of standards),
- the level of internal sponsorship available (because of the time and money involved in the more proactive strategies) and
- timing.

All these factors contribute to a cost/benefit ratio analysis that should drive the selection of a standards engagement strategy.

3.6 Standards Adoption and the Product Lifecycle

New standards may emerge once a product is already in the market. In that case, a supplier needs to decide whether to make its product compliant to maintain its appeal to the market and avoid an attack by competitors. However, in general, relevant standards should be identified and made part of the product's design *at the beginning* of the product lifecycle. This can be done for engineering reasons (leverage open-source code, accelerate development) or marketing reasons (respond to customer demand, position interoperability as a competitive advantage).

Early engagement requires collaboration between the relevant standards experts with engineering stakeholders such as architects, product managers and developers. These stakeholders can then evaluate the existing relevant standards landscape and shape their product plans to align quickly with the industry–thus minimizing time-to-value and maximizing customer adoption.

In summary, standards engagement provides value by exhibiting thought leadership, marketing opportunities, early access to engaged customers and insight into emerging technologies. Sitting on the sidelines and waiting for standards to "happen to you" is a risky option. It may seem the

cheaper strategy in the short term, but the price to be paid ultimately may be high. Instead, IIC member companies are encouraged to take part in, and lead as appropriate, the development of standards to receive the benefits we outlined earlier.

3.7 STANDARDS STRATEGY FOR END USERS

End users of IIoT products or solutions can adapt the above strategy recommendations to their own purpose. Most aspects are relevant to their situation.

Those end user organizations should consider the following:

- *Establish a company policy to mandate and use applicable standards*. Standards are key to vendor independence and reduced costs of integration. Applying IT standards to the OT organization will also result in enhanced and more secure deployed systems.
- *Create and maintain a list of standards that suppliers should comply with*. This requirement should be implemented in collaboration with the sourcing department, so it is included in all requests for proposals or quotations.
- *Establish and measure a metric of success*. This may be in terms of the cost to integrate non-standard products, training costs, the number of different protocols and interfaces "spoken" by the company's system, the number of remaining non-compliant suppliers, etc.
- *Assign a person or group to monitor the standards space*. This function maintains the policy, the list of standards, and the metrics. It will also propose which standards organizations to join to influence the development of those standards from an end user's perspective, balancing the interests of the suppliers.
- *Participate in industry consortium activities*. In addition to learning from their peers, members help drive the development of new standards by providing use cases and requirements and by supporting testbeds for prototype technologies.

4 EXECUTING THE STANDARDS STRATEGY

Having defined its strategy among the options and using the considerations presented in Section 3, that strategy must be turned into a set of concrete actions. In this section, we detail both the process and organization changes to implement in order to make the strategy a reality.

4.1 ASSESS THE PRODUCT PORTFOLIO

The first step is to inventory the building blocks of *the organization's entire product portfolio*. Each of these building blocks is then categorized according to its relationship to standards. The resulting inventory, which needs to be maintained as both the products and the standards will change, contains for each entry the kinds of information shown in Table 4-1.

Specification	Description
Building Block	Unique name of a hardware, firmware, or software component, as typically found in a bill of materials
Version	Version number of the component
Specification	A reference to a document, or documents, describing the component specifications
Source Type	One of the following: • commodity supply (can be procured from multiple suppliers whose products are interchangeable), • proprietary supply (procured from a specific supplier, not interchangeable, • open source (software published by a community of developers) or developed internally or by a contractor.
Source	Name of the internal or external provider of this particular version of the product
Status	One of the following: • legacy–is no longer incorporated in new products, • no applicable standards exist, • not to be standardized (proprietary by intent), • standard-compliant, • non-standard, no adequate standard is available, to be redesigned or replaced by a standard-compliant component or • non-standard, no adequate standard is available, but development of a new standard is recommended
Standards compliance	List of standards (and their version) with which the component is compliant

Table 4-1: Organizational Building Block Inventory

Such a catalog of architectural building blocks constitutes *one of the sources* that can be used to generate a separate *catalog of standards* in which the organization has a dependency or interest.

4.2 Implement a "Standards Watch" Function

The above bottom-up approach (finding out what standards are used in existing products) is insufficient, since by design it will not expose standards that none of the products currently follow. Therefore, it needs to be complemented by a top-down approach, in which a technology-watch role actively researches what standards exist "out there" and should be followed, and which ones need help in coming to light.

Large companies should have a centralized team dedicated to supporting the business activities related to standards, typically organized under the Office of the Chief Technical Officer. In some organizations an IP lawyer is part of the central team. The most modern approach is that the legal department supports the central team with issues like antitrust or intellectual property.

In small companies, the standards watch function may be ensured by a single person or by a small committee of people dedicated to this activity part-time.

This “standards watch” capability can use a variety of sources, such as:

- papers and articles in professional journals,
- presentations at conferences,
- commercial literature from competitors,
- feedback from marketing and sales,
- direct discussions with customer personnel in technology roles,
- attendance at open meetings of standards organizations and
- participation in industry consortia (such as the IIC).

It helps to build a “shopping list” of potential areas of standardization because IIoT is a vast domain, ranging from sensor communication to data analytics and machine learning, so there are many standards to consider. To “divide to conquer,” one can examine the various parts of IIC’s Industrial Internet Reference Architecture (IIRA) for useful guidance. Table 4-2 provides a potential (but not exhaustive) checklist of technology areas to consider.

Technology	Standards
Operating Systems	In the past, SCADA systems were based on proprietary logic control, but modern IoT systems use standard operating systems, such as Linux, and are sometimes stripped of unnecessary components to run in resource-constrained environments.
Cloud Deployment Technologies	Emerging standards for cloud interoperability and orchestration will play an important role in avoiding vendor lock-in. For example, the Linux Foundation offers the Open Container Initiative (OCI) and the Cloud Native Computing Foundation (CNCF) and hosts the Container Network Interface (CNI) project. The Kubernetes project aims at providing portability and orchestration of workloads in multi-cloud environments.
Data Management	While standards for relational data management, such as Structured Query Language (SQL), have been in existence for decades, data analytics and machine learning require new structures better suited to those jobs. Ontologies and knowledge graphs are the key forms of knowledge representation that form the foundation for data understanding, not just data storage and retrieval. Standards such as RDF (Resource Description Framework), OWL (Web Ontology Language) or SPARQL–the query language for RDF databases--are increasingly important. Based on these languages, several initiatives are creating standards for semantic building blocks in the specific context of various industries. The general methodology for the creation of business vocabularies can be found, in particular, in ISO 15000-5:2014 (*https://www.iso.org/standard/61433.html).* More generally, the conceptual modeling of all the information acquired and processed by an IoT system is a fundamental necessary step, and the Unified Modeling Language (UML) is the unchallenged standard to perform this activity. Data quality is essential to being able to make proper decisions that a system will execute with minimal “human in the loop” involvement. In this respect, the work of ISO TC 184/SC 4 on industrial data as well as the ISO 8000 data quality standards are likely to be critical. SC 4 includes working groups responsible for product characteristics, oil/gas/process/power industries, industrial data quality and digital manufacturing.
Systems Modeling and Interoperability	Systems Modeling Language (SysML) is based on UML, is widely supported by vendor tools and addresses much more than the data model. A new version, SysML v2, under development in 2020-21, will add many important modeling extensions. Asset-intensive systems (power plants, refineries, oil platforms, ships…) present their own challenges. Their cost mandates a long operational life, which means that original designs may only be documented on paper, and the history of the system as-designed, as-built and as-maintained may have been lost. The work of the MIMOSA industry association on the Open Industrial Interoperability Ecosystem (OOIE), tightly related to the ISO 15926 standard, is one noteworthy standard approach.

Technology	Standards
Information Exchange	Reliable and secure real-time data communication is now covered by multiple competing standards. This is a rich field, with many interoperable implementations, and choosing between these protocols based on specific system requirements can be a challenge. This reinforces the need for the active "standards watch" function and potentially for involvement in the corresponding organizations. Some of the best-known standards for communication between the various components of an IoT system are MQTT (Message Queuing Telemetry Transport), developed by OASIS and adopted as ISO/International Electrotechnical Commission (IEC) 20922; OPC/UA (Open Platform Communications Unified Architecture), developed by the OPC Foundation and standardized as IEC 62541; DDS, an OMG standard. The format of the information that flows from sensors to systems is also the object of standardization efforts. IIC provided the motivation for OMG to develop the SENSR (Simple Electronic Notation for Sensor Reporting) standard, adopted in 2019.
Security	Many of the same approaches and standards in the area of non-IoT system security can also be used in IoT system security. The authentication of devices and the encryption of data traffic, especially for sensors located "in the field" and outside of physically protected areas, can be handled using Public Key Infrastructure (PKI) based on IETF Request for Comments (RFCs) 2510 and 2511. For access to cloud resources, the recommendations of the Cloud Security Alliance (CSA) are key. The security extensions of information exchange protocols (for example, DDS-Security) must also be considered.

Technology	Standards
Artificial Intelligence and Machine Learning	AI/ML is an area in which there are few published standards yet (and no real adoption), but various organizations are working to develop them. ISO/IEC JTC 1/SC 42, the ISO subcommittee on AI, has mostly focused on a big data reference model, but started in 2020 to focus on AI trustworthiness. The OMG initiated an Artificial Intelligence Platform Task Force at the end of 2019 to remedy this. For OMG, the goal of AI standards is to "reduce the friction" in: • metadata for training data sets, • a standard format for the exchange of classifier data, • neural network sensitivity metrics (how much can a small change in one input cause a major change to a recommendation) and • the way in which a machine learning algorithm can provide a human-readable explanation of how it reached its decision. Standards for "ethical AI" are also being considered by some organizations, and the American Council for Technology and Industry Advisory Council (ACT-IAC) has developed a scorecard to address this. It is important for such standards not to restrict the creativity and generation of novel intellectual property by companies that develop AI solutions.

Table 4-2: Checklist of Technology Areas and Related Standards

Both the standards watch capability and the study of existing product architectures lead to a standards inventory, which contains entries a shown in Table 4-2:

Standards Inventory	
Standard name	Name of the standard
Version	Version of the standard
Responsible organization	Source of the standard (IEEE, ISO, OMG, Open Group, etc.)
Purpose and benefit	Rationale to adhere to this standard
Used in	List, inverted from the previous table, of the products that adhere to this standard (if any)
Adoption level	One of the following: • retired (superseded, or found to be detrimental; must not be used anymore), • obsolescent (must not be used in *new* products), • active (is currently recommended whenever possible), • emergent (to be introduced selectively when advantageous) or • desirable (does not exist but would bring benefits).

Table 4-2: Standards Inventory

Finally, the (typically short) list of "desirable" standards can be filtered into:

- those that are mature and require no particular attention,
- those that need to be watched because they keep evolving, and the designers need to be made aware when the market requires an upgrade to a newer version or
- those few which the company should take an active role in creating.

4.3 Define the Enterprise Standards Process

The flow of requirements and contributions between the parties involved can be represented by the graph in Figure 4-3, in which the "north and east" parts (blue ovals and arrows) represent the organizations and flows that exist in organizations regardless of whether they have formalized a standards watch function, while the "south, west and center" parts (brown ovals and arrows) represent the additional groups and interactions that result from adding this function.

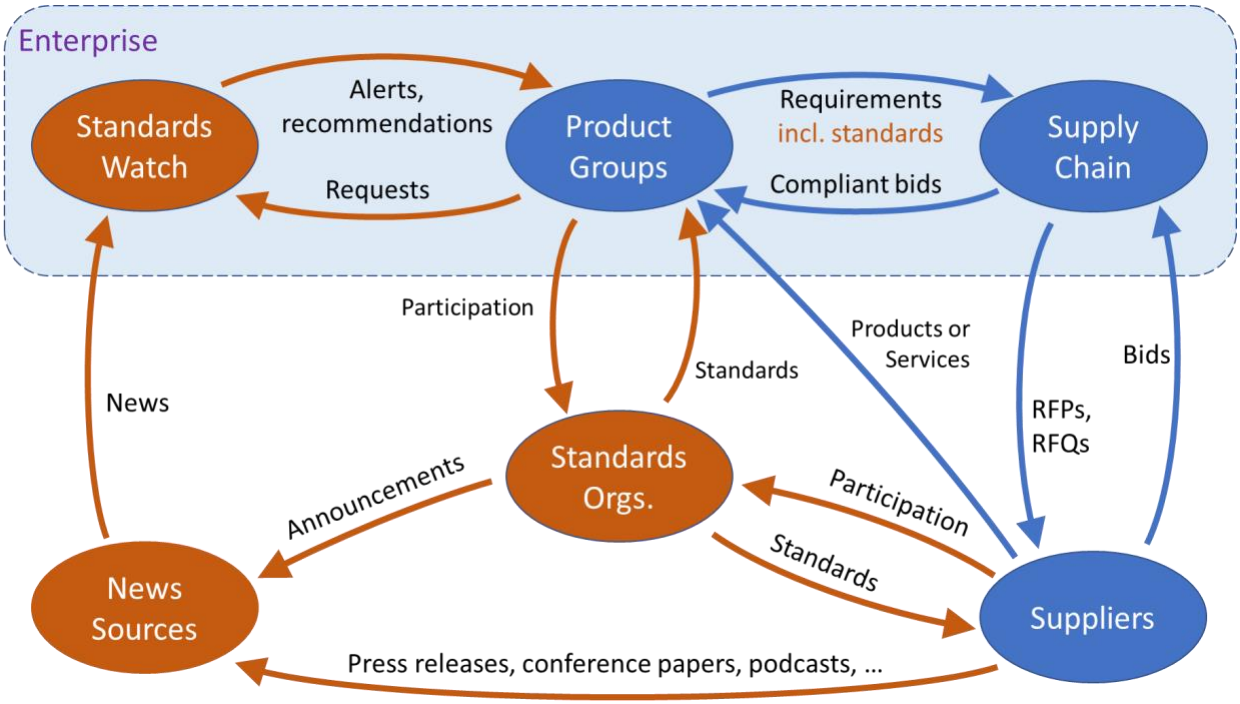

Figure 4-3: Flow of Standards Requirements and Contributions

Note: "Standard Orgs." In the diagram refers to both formal standards organizations and to consortia; their products, shown here as "standards," include formal standards as well as other specifications.

Organizations that choose to follow the strategy of adopting or contributing to standards can use the above diagram to verify that their product groups, supply chain department and the standard-watch group implement all the necessary collaborations to execute that strategy.

We specifically included the supply chain department to highlight the role it can play in adding standards compliance to the requirements expressed in Request for Proposals (RFPs), and in screening received bids for adherence to such requirements. It just becomes an important factor in the implementation of the strategy.

4.4 Governance of Standards Activities

As the diagram above shows, a proactive standards strategy will result in multiple efforts throughout the company to watch, disseminate, document, adopt, adapt, and influence standards. To avoid duplication of efforts (or worse, conflicting efforts), certain coordination and governance mechanisms must be put in place.

Tracking: A supplier may participate in dozens of standards-related activities. It is important that a company know which SDOs it has joined, under which membership agreements, and over what time period. Tracking the company's participation ensures that the company can renew its participation in a timely manner, replace a delegate who has left the company, and disengage if the risk of sharing information with competitors exceeds the advantage to be gained.

IP protection: Failure to comply with participation agreements, including the failure to disclose certain intellectual property rights (IPR) when contributing technology to a standard, result in a variety of legal risks. Mature organizations participating in standards have procedures in-place to vet the IP aspect of each participation and do so with underlying IP strategies. Development and implementation of a sound policy is essential and should be executed by the legal department. It is equally important to identify those employees who have participated and made contributions that may create encumbrances on intellectual property rights and may give rise to additional IP disclosure obligations. IP commitments and encumbrances should be tracked to ensure that commercial agreements and transactions account for these encumbrances.

Community of practice: Participants engaged in SDO activities are often dispersed throughout the company (at least in a large organization) and work in specific product or business groups. Building a community of practice of these participants helps them share best practices and gives them a sense of identity. It also allows direct cross-pollination of efforts since the various standards areas often overlap (for example, information exchange and security).

Education and training: Both business and legal resources should be allocated to educate the personnel participating in SDOs in both the business strategy of the company and the intricacies of IP protection.[5] Many larger companies have developed training programs to teach the company's engagement and approval policies or antitrust compliance. In some cases, advisory resources may be needed to participate in SDO governing bodies such as steering committees or legal working groups to execute effectively on the company's standards' strategy since they have greater visibility of the overall strategy. Business should drive the engagements.

Policy and outreach: Some organizations allocate business, technical and legal resources to work with the government and community affairs offices. Doing so helps ensure that legislators are informed about the impact of their efforts, and that public policy does not duplicate or contradict industry standards efforts or become unduly burdensome.

5 CONCLUSION

We have demonstrated the business case and established strategies for adopting existing standards and participating in standards development. To realize these benefits, we recommend that you:

- review the use of standards in your own organization, and discuss with leadership the adoption of strategies recommended in this document,
- provide feedback on your own initiatives and experiences in the use and development of standards to the IIC Standards Task Group,

[5] Some companies hire standards professionals to represent their interests in SDOs.

- volunteer as a Liaison Officer between the standards development organizations you engage with and the IIC,
- suggest to the Standards Task Group new liaison opportunities with the standards development organizations you participate in and
- participate in the evolution of this document.

APPENDIX A: CATALOG OF STANDARDS ORGANIZATIONS

This Appendix completes Section 2 of the paper by providing an example list of SDOs, industry consortia and associations that play a role in the definition and adoption of standards relevant to the Industrial Internet.

A.1 STANDARD DEVELOPMENT ORGANIZATIONS

Abbreviation	Full Name & Website	Focus
AFNOR	Association Française de Normalisation (French Standards Association) *www.afnor.fr*	As France's standardization coordinator, AFNOR has a clear-cut goal: contribute to the dissemination of best practices and effective solutions for the benefit of all. To this end AFNOR Standardization informs and guides all those who, through their involvement in the development of voluntary standards, wish to enable development of projects, activities and sectors under optimal conditions and thereby contribute to building the economy and society of tomorrow.
BSI	British Standards Institute	
DIN	Deutsches Institut für Normung e.V. (German Institute for Standardization) *www.din.de/en*	The German national organization for standardization and is the German ISO member body. DIN is a German Registered Association (e.V.) headquartered in Berlin. There are currently around 30,000 DIN Standards, covering nearly every field of technology.
DKE	German Electrotechnical Standards Board *www.dke.de/en*	The expertise centre for electrotechnical standardization in Germany.
ECLASS	ECLASS *www.eclass.eu/en*	ECLASS has established itself internationally as the only ISO/IEC-compliant industry standard and is thus the worldwide reference-data standard for the classification and unambiguous description of products and services.

Abbreviation	Full Name & Website	Focus
ETSI	European Telecommunications Standards Institute *www.etsi.org*	ETSI produces globally-applicable standards for Information and Communications Technologies (ICT), including fixed, mobile, radio, converged, broadcast and internet technologies. Examples of standards are Global System for Mobile Communications (GSM™), Digital Enhanced Cordless Telecommunications (DECT™), Smart Cards and more.
IEC	International Electrotechnical Commission *www.iec.ch*	A non-profit international standards organization that prepares and publishes international standards for a vast range of technologies.
IEEE	Institute of Electrical and Electronics Engineers *www.ieee.org*	IEEE and its members inspire a global community to innovate for a better tomorrow through its more than 423,000 members in over 160 countries, and its highly cited publications, conferences, technology standards, and professional and educational activities. IEEE is the trusted “voice” for engineering, computing, and technology information around the globe.
IETF	Internet Engineering Task Force *www.ietf.org*	The premier internet standards body, developing open standards through open processes. It is a large open international community of network designers, operators, vendors, and researchers concerned with the evolution of the internet architecture and the smooth operation of the internet.
ISA	International Society of Automation *www.isa.org*	A non-profit professional association founded in 1945 to create a better world through automation. ISA advances technical competence by connecting the automation community to achieve operational excellence.
ISO	International Organization for Standardization *www.iso.org*	An independent, non-governmental international organization with a membership of 164 national standards bodies. ISO has published 22668 International Standards and related documents, covering almost every industry, from technology, to food safety, to agriculture and healthcare.

Abbreviation	Full Name & Website	Focus
ITU	International Telecommunication Union www.itu.in	The United Nations specialized agency for information and communication technologies (ICTs). Founded in 1865 to facilitate international connectivity in communications networks, we allocate global radio spectrum and satellite orbits, develop the technical standards that ensure networks and technologies seamlessly interconnect, and strive to improve access to ICTs to underserved communities worldwide. Every time you make a phonecall via the mobile, access the internet or send an email, you are benefiting from the work of ITU.
OASIS	Organization for the Advancement of Structure Information Standards *www.oasis-open.org*	The goal of OASIS is to promote the adoption of product-independent standards for information formats such as Standard Generalized Markup Language (SGML), Extensible Markup Language (XML) and Hypertext Markup Language (HTML). Currently, OASIS is working on the development, convergence, and adoption of standards for security, IoT, energy, content technologies, emergency management and other areas. They are helping develop Advanced Message Queuing Protocol (AMQP) and Message Queuing Telemetry Transport (MQTT), which are directly related to IoT advancements.
OMG	Object Management Group *www.omg.org*	The mission of OMG is to develop technology standards that provide real-world value for thousands of vertical industries. OMG is dedicated to bringing together its international membership of end-users, vendors, government agencies, universities and research institutions to develop and revise these standards as technologies change throughout the years.
oneM2M	oneM2M *www.onem2m.org*	The leading international standardization body for machine-to-machine (M2M) communication and IoT. It was established through an alliance of standards organizations to develop a single horizontal platform for the exchange and sharing of data among all applications. oneM2M is providing an interworking framework and enabling re-use of what is already available as much as possible.

Abbreviation	Full Name & Website	Focus
OPC	OPC Foundation *www.opcfoundation.org*	The goal of OPC Foundation is to create technologies that allow information to be easily and securely exchanged between diverse platforms from multiple vendors and to allow seamless integration of those platforms (without software development) primarily for the purpose of Industrial Automation (I4.0). OPC provides products that include Software (servers, clients, toolkits) and Services from OPC members. Apart from these products and services, OPC provide certification for interoperability among various OPC products from different vendors. The OPC-UA technology is standardized at IEC 62541.
W3C	Word Wide Web Consortium *www.w3.org*	An international community that develops open Web standards to ensure the long-term growth of the Web.

A.2 INDUSTRY CONSORTIA AND ASSOCIATIONS

Abbreviation	Full Name & Website	Focus
AII	China Alliance of Industrial Internet *http://en.aii-alliance.org/*	The industrial internet is a major component in the strategy for the "China Manufacturing 2025" and "Internet + Collaborative Manufacturing" initiatives as a key instrument in the transformation and upgrading of advanced manufacturing industry in China and abroad.
America Makes	America Makes *www.americamakes.us*	The U.S. leading and collaborative partner in additive manufacturing and 3D printing technology research, discovery, creation, and innovation. Structured as a public-private partnership, we innovate and accelerate AM/3DP to increase our nation's global manufacturing competitiveness.
BITKOM	Bundesverband Informationswirtschaft, Telekommunikation und neue Medien e. V. *www.bitkom.org*	Bitkom is Germany's digital association. Founded 1999 in Berlin, they represent more than 2,600 companies of the digital economy. Its membership spans more than 1,000 SMEs, over 500 startups and virtually all global players. Bitkom advocates the digitisation of the economy, the society and public administration.

Abbreviation	Full Name & Website	Focus
CESMII	Clean Energy Smart Manufacturing Innovation Institute *www.cesmii.org*	Smart Manufacturing (SM) enables all information about the manufacturing process to be available when it is needed, where it is needed, and in the form it is needed across the entire manufacturing value-chain to power smart decisions. Islands of efficiency become interoperable, networked, and resilient solutions to drive transformational manufacturing enterprise performance for any size, level of technical sophistication, or resource availability at lower cost.
Energistics	*https://www.energistics.org/*	Energistics (formerly the Petroleum Open Standards Consortium [POSC]) provides the global upstream oil and gas industry with an open consortium to define, develop and maintain data standards. Energistics is dedicated to informing, educating and supporting all stakeholders to ensure a rapid and effective adoption of the standards in the pursuit of interoperability, efficiency and data integrity.
EUCEP	European Circular Economy Stakeholder Platform *www.circulareconomy.europa.eu/platform/*	A joint initiative by the European Commission and the European Economic and Social Committee
IIC	Industrial Internet Consortium www.iiconsortium.org	Define IoT standards requirements, develop reference architectures and frameworks necessary for interoperability. Create new industry use cases and run testbeds; build an ecosystem. Define and influence the international development standards process for internet and industrial systems
NAMUR	User of Automation Technology in Process Industries *www.namur.net/en*	NAMUR, the "Association of Automation Technology in Process Industries", is an international association of user companies (established in 1949) and represents their interests concerning automation technology. NAMUR has over 150 member companies. Added value through automation engineering drives all NAMUR member company activities.
OGC	Open Geospatial Consortium *www.ogc.org*	The Open Geospatial Consortium (OGC) is an international consortium of more than **500** businesses, government agencies,

Abbreviation	Full Name & Website	Focus
		research organizations, and universities driven to make geospatial (location) information and services FAIR - Findable, Accessible, Interoperable, and Reusable.
OSGi	Open Services Gateway initiative Alliance. *www.osgi.org*	The OSGi specification describes a modular system and a service platform for the Java programming language that implements a complete and dynamic component model. The alliance is in the process of starting an IoT workstream.
PI4.0	Plattform Industrie 4.0 *www.plattform-i40.de*	The Plattform Industrie 4.0 is led by the German Government. The associations BITKOM, VDMA and ZVEI support the efforts. The Learning Networks Industry complements the Plattform to run testbeds and the Standardization Council works to get the requirements standardized.
PLS	Plattform Lernende Systeme (Platform for Learning Systems) *www.plattform-lernende-systeme.de*	Launched by the German Federal Ministry of Education and Research (BMBF) in 2017 at the suggestion of The German Academy of Science and Engineering (acatech) to design self-learning systems for the benefit of society. The members are organized into Working Groups and a Steering Committee that consolidates the current state of knowledge about self-learning systems and artificial intelligence. They point out developments in industry and society, analyze the skills that will be needed in the future and use application scenarios to demonstrate the benefit of self-learning systems. A managing office at acatech coordinates the work.
VDE	Verband der Elektrotechnik, Elektronik und Informationstechnik (Association for Electrical, Electronic and Information Technologies) *www.vde.com/en*	VDE develops ideals for a future emerging here and now—in an extraordinary network of research, science, industry, safety and education.
VDI	Verein Deutscher Ingenieure (Association of German Engineers) *www.vdi.de*	Engineers need a strong network that supports, advances and represents them in their work. That is exactly the task that we in VDI–The Association of German Engineers–take on. We have been reliably supporting engineers for

Abbreviation	Full Name & Website	Focus
		more than 160 years. We provide them with a professional base and maintain a lively network at regional, national and international Levels.
VDMA	Verband Deutscher Maschinen- und Anlagenbau e.V. (Association for Mechanical Engineering Industry) *www.vdma.org*	VDMA represents more than 3,200 member companies in the SME-dominated mechanical and systems engineering industry in Germany and Europe.
ZVEI	Zentralverband Elektrotechnik- und Elektronikindustrie e.V. (German Electrical and Electronic Manufacturers' Association) *www.zvei.org*	ZVEI is one of the most important industrial associations in Germany. It represents the interests of a high-tech sector with a very wide and extremely dynamic product portfolio. ZVEI is committed to the common interests of the electrical industry in Germany and at the international level. This commitment is supported by the involvement of around 160 employees in the main office and about 5,000 employees of the member companies in an honorary capacity.

AUTHORS AND LEGAL NOTICE

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