Vertical Standards Landscape

An Industry IoT Consortium Reference

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1 OVERVIEW

In a previous paper entitled "Global Industry Standards for Industrial IoT[1]," published in mid-2021, the IIC Standards Task Group proposed the elements of a standards engagement strategy for providers and customers of industrial IoT (IIoT) solutions.

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:

1. Avoid a proliferation of one-to-one interfaces to connect systems together
2. Achieve the integration of operational technology (OT) with enterprise systems that conform to IT standards, or within a system of systems
3. Avoid vendor lock-in by increasing the substitutability of components
4. Meet the requirements of regulatory agencies, which mandate standards to increase safety and security
5. Avoid the cost of training new employees on proprietary technologies.

Organizations (such as IIC members) must respond to these imperatives by defining a standards strategy and taking certain actions to execute it. These actions can be limited to identifying and adopting relevant standards, but they can also extend to active participation in the definition and evolution of those standards.

IIC does not develop standards, but works closely with SDOs, including through formal liaison agreements, to provide requirements, publish best practices for standards use, and construct testbeds and technology showcases to demonstrate standards-based capabilities.

This paper addresses the question of which standards are relevant to certain vertical industries as they design and deploy IIoT capabilities. The next page explains the rationale behind the choice of those vertical industries. Horizontal or cross-industry standards will be considered in a separate IIC document. In particular, IoT systems raise data protection issues that are increasing addressed through regulations, such as the General Data Protection Regulation (GDPR) and others, that are neither IoT-specific nor domain-specific.

The list of 35 standards (or standards series) that follow was compiled from IIC member submissions, from the authors' own research, and from external sources such as the European Union Observatory of Standard (EUOS)[2] landscape documents, in particular the one about digital

[1] *https://www.iiconsortium.org/pdf/IIC_Global_Standards_Strategy_Whitepaper.pdf*
[2] *https://www.standict.eu/euos*

twins published in 2022[3]. The landscape is divided into three groups in order to provide clear guidance to the reader:

1. Section 2 lists standards that are both very specific to one domain and related to IoT systems.
2. Section 3 lists standards that, while not IoT-specific, provide support for domain-specific IoT developments.
3. Section 4 further broadens the scope by listing standards that support multiple domains.

The paper concludes with recommendations and with a call to submit additional or revised material for future updates. The standards landscape can change quickly, and the reader is urged to seek the latest status of the standards listed here, and search for new standards that may have emerged since the publication of this document.

1.1 About the Classification of Standards in this Document

Each entry for a standard indicates which vertical domain it pertains to. By "domain," we mean an industrial sector in which the IIC is currently active, in particular through the existence of a dedicated Task Group. At the time this initial version of the Vertical Standards Landscape was developed, the domains in question were *transportation, healthcare, manufacturing,* and *energy.* We further subdivided energy into the electricity sector (utilities) and the oil and gas sector, since they have little in common.

If and when additional domains are addressed by IIC in the future, this landscape should be revised to add relevant sections. An example of a domain in which we have identified numerous relevant standards, but which is currently not an area of focus by the IIC, is the Smart Cities industry.

Each standard entry is also labeled as addressing one of more "scopes" taken from this list:

- Guidelines
- Reference Architecture
- System Architecture
- Information Modeling
- Data and Information Management
- Data Representations
- Communications/Networking
- Interoperability
- Enterprise/Systems Integration
- Analytics and AI
- Security and Trustworthiness

[3] *https://www.standict.eu/landscape-analysis-report/landscape-digital-twins*

Whether a standard is directly related to Industrial IoT is sometimes ambiguous. In general, we included in this section references that explicitly mention in their description one of the terms “IoT” (or “Internet of Things”), “sensors,” “actuators,” or “devices,” or strongly suggest that the models, protocols, data formats, etc., contained in the standard were directly related to those concepts.

Finally, note that the word “standard” is used with different degrees of rigor by different organizations. For some, a document listing use cases, or a set of guidelines, is a standard. For others, a standard must include normative content – with “shall” and “should” verbs that compel the targeted audience to adopt certain models, architectures, formats, or protocols. Deciding which documents qualify as standards for the purpose of this document is a somewhat subjective exercise.

1.2 INDEX OF STANDARDS LISTED

Name	Reference	Section
Asset administration shell for industrial applications – Part 1: Administration shell structure	BS IEC 63278-1	2.1
Automation systems and integration — Digital twin framework for manufacturing	ISO 23247-1:2021	2.1
AutomationML	IEC 62714	3.1
Batch control – Part 2: Data structures and guidelines for languages	IEC 61512	3.1
Calculations of savings and energy efficiency	CENELEC	3.3
Communication networks and systems for power utility automation	IEC 61850	3.3
eHEALTH Architecture – Analysis of user service models, technologies and applications supporting eHealth	ETSI TR 102 764	3.2
Energistics Transfer Protocol (ETP)	Energistics	3.3
Energy management systems—Requirements with guidance for use	ISO 50001	3.3
Enterprise control system integration – Part 3: Activity models of manufacturing operations management	IEC 62264	3.1
EPC Information Services (EPCIS)	GS1	4
Facility smart grid information model	ISO 17800	2.4
Fast Healthcare Interoperability Resources (FHIR) v4.0.1	HL7	3.2
Health informatics – Point-of-care medical device communication	ISO/IEEE 11073	2.3
HL7 Version 2 messaging standard	HL7	2.3
Industrial process measurement, control, and automation – Life cycle management for systems and components	IEC 62890	3.1
Industrial process measurement, control and automation – Smart Manufacturing – Part 2: Use cases	IEC/TR 63283-2	2.1
Industrie 4.0 Service Architectures – Part 1: Basic Concepts of an Interaction-based Architecture	DIN SPEC 16593-1	2.1

Name	Reference	Section
Industrial process measurement, control, and automation – Life cycle management for systems and components	IEC 62890	3.1
Information security controls for the energy utility industry	ISO/IEC 27019	2.4
IoT Reference Architecture	ISO/IEC 30141	4
KNX Protocol	KNX, CENELEC, EN 50090, ISO 14543-2	2.4
Oil and Gas Interoperability Technical Specification	ISO 18101	3.3
On-Board System Requirements for V2V Safety Communications	SAE J2945/1	2.2
PackML	ISA	3.1
Patient Care Device (PCD) Profiles	IHE International	2.3
SAREF extension investigation – Requirements for industry and manufacturing domains	ETSI TR 103 507	4
Security for Industrial Automation and Control Systems	ISA 62443	4
Security, Network Services and Multi-Channel Operation	IEEE 1609.x	2.2
SHIP (Smart Home IP) and SPINE (Smart Premises Interoperable Neutral Message Exchange)	EEBUS Initiative	2.4
Smart Energy Profile Application Protocol	IEEE 2030.5	2.4
Smart Manufacturing – Reference Architecture Model Industry 4.0 (RAMI4.0)	IEC PAS 63088	3.1
SmartM2M – Extension to SAREF – Part 1: Energy Domain	ETSI TS 103 410-1	3.3
V2X Communications Message Set Dictionary	SAE J2735	2.2
Use cases for cross-domain data usability of IoT devices	ETSI TR 103 778	4
Validation protocol for walking speed	ISO/DIS 24227	2.3
Vehicle ground integrated communication system (LTE-M) of Urban Rail Transit	CAMET	2.2
Wireless Access in Vehicular Environments (WAVE)	IEEE 802.11p	2.2
WITSML (Well-site Information Transfer Standard Markup Language) 2.0	Energistics	3.3

2 IoT- and Domain-Specific Standards

2.1 Manufacturing

Source	DIN
Name	DIN SPEC 16593-1 – Reference Model for Industrie 4.0 Service Architectures – Part 1: Basic Concepts of an Interaction-based Architecture
Date	2018
URL	*www.beuth.de/en/technical-rule/din-spec-16593-1/287632675*
Domain	Manufacturing
Scope	System Architecture
Description	Concepts of component interaction in Plattform Industrie 4.0
Comments	Well adopted throughout the industry
Submitter	Kym Watson (Fraunhofer IOSB), *kym.watson@iosb.fraunhofer.de*

Source	ISO
Name	ISO 23247-1:2021 Automation systems and integration — digital twin framework for manufacturing • Part 1: General principles • Part 2: Reference architecture • Part 3: Basic information attributes • Part 4: Technical requirements for information exchange
Date	2021
URL	*https://www.iso.org/obp/ui/#iso:std:iso:23247:-1:ed-1:v1:en*
Domain	Manufacturing
Scope	Guidelines, Reference Architecture, Data Representation
Description	"The ISO 23247 series defines a framework to support the creation of digital twins of observable manufacturing elements including personnel, equipment, materials, manufacturing processes, facilities, environment, products, and supporting documents."
Comments	Digital twin framework
Submitter	Alan McGibney (MTU), *alan.mcgibney@mtu.ie*

Source	IEC TC 65 (Automation)
Name	BS IEC 63278-1 Asset administration shell for industrial applications – Part 1: Administration shell structure
Date	2020
URL	• *https://www.en-standard.eu/20-30406975-dc-bs-iec-63278-1-asset-administration-shell-for-industrial-applications-part-1-administration-shell-structure/* • *https://www.plattform-i40.de/IP/Redaktion/EN/Standardartikel/working-group-01.html*
Domain	Manufacturing
Scope	Information Modeling
Description	Defines a standardized digital representation of assets of manufacturing enterprises, including produced products. The Asset Administration Shell is a "standardized connector" that enables two or more systems or software applications to exchange information and to mutually use the information that has been exchanged in a trusted and secure way.
Submitter	Alan McGibney (MTU), *alan.mcgibney@mtu.ie* European Union Observatory on Standards (listed in Digital Twin Landscape)

Source	IEC TC 65 (Automation)
Name	IEC/TR 63283-2 Industrial-process measurement, control and automation – Smart Manufacturing – Part 2: Use cases
Date	March 2022
URL	*https://webstore.iec.ch/publication/66315*
Domain	Manufacturing
Scope	Guidelines
Description	Analysis of the impact of smart manufacturing on the daily operation of an industrial facility, based on a set of use cases in the manufacturing industry. This covers not only the automation and control of the production system, but also the supporting processes of ordering, supply chain management, design, engineering and commissioning, operational technology, life cycle management, and resource management.
Submitter	European Union Observatory on Standards (listed in Digital Twin Landscape)

2.2 TRANSPORTATION

Source	China Association of Metros (CAMET)
Name	Specification for vehicle ground integrated communication system (LTE-M) of Urban Rail Transit, consisting of: • T/CAMET 04005 • T/CAMET 04006 • T/CAMET 04007 • T/CAMET 04008 • T/CAMET 04009 • T/CAMET 040010 • T/CAMET 040011 • T/CAMET 040012 • T/CAMET 040013
Date	2018
URL	*www.camet.org.cn/bzbzgg/4227*
Domain	Transportation
Scope	Communications / Networking
Description	The standard specification of urban rail transit vehicle ground integrated communication system (LTE-M) involves system requirements, products, interfaces, testing, project implementation, etc., which requires overall planning, Point-to-Plane combination and step-by-step implementation. Relying on urban rail communication signal system engineering and equipment procurement, it will be gradually implemented in stages. The objective of this project is to complete the preparation of LTE-M system series specifications and establish a standard specification system for LTE-M system requirements, system and product technology, interface, test and engineering.
Comments	Related to the LTE for Metro IIC testbed
Submitter	Xueting Kang (Huawei), *kangxueting@huawei.com*

Source	Multiple
Name	Dedicated Short-Range Communications (DSRC) Standards: • IEEE 802.11p amendment for wireless access in vehicular environments (WAVE) • IEEE 1609.2, 1609.3, and 1609.4 standards for Security, Network Services and Multi-Channel Operation • SAE J2735 V2X Communications Message Set Dictionary • SAE J2945/1 On-Board System Requirements for V2V Safety Communications
Date	2021 (IEEE standards) and 2020 (SAE standards)
URL	• *https://ieeexplore.ieee.org/document/5514475* (IEEE 802.11p) • *https://ieeexplore.ieee.org/document/7426684* (IEEE 1609.2) • *https://ieeexplore.ieee.org/document/7458115* (IEEE 1609.3) • *https://ieeexplore.ieee.org/document/7435228* (IEEE 1609.4) • *https://www.sae.org/standards/content/j2735_202007* (SAE J2735) • *https://www.sae.org/standards/content/j2945/1_202004/* (SAE J2945/1)
Domain	Transportation / Automotive
Scope	Communications/Networking
Description	DSRC is a U.S. Department of Transportation (DOT) project based on ISO's Communications Access for Land Mobiles (CALM) architecture for vehicle-based communication networks, particularly for applications such as toll collection, vehicle safety services, and commerce transactions via cars.
Comments	These six closely related standards were grouped here for convenience.
Documents	Also see this analysis paper from IEEE: *https://ieeexplore.ieee.org/document/5888501 (2011*
Submitter	Claude Baudoin (cébé IT & Knowledge Mgmt.), *cbaudoin@cebe-itkm.com*

2.3 HEALTHCARE

Source	ISO/TC 159/SC 3 (Anthropometry and biomechanics)
Name	ISO/DIS 24227 Validation protocol for walking speed
Date	t.b.d. (at Draft International Standard stage as of 2022)
URL	*www.iso.org/standard/78134.html*
Domain	Healthcare
Scope	System Architecture
Description	Accuracy evaluation protocol for daily living walking speed extracted from sensor systems that measure human body motion
Comments	It is currently unclear whether this upcoming standard specifically deals with communication systems and therefore how IoT-specific it is.
Submitter	Erin Bournival (Dell Technologies), *erin.bournival@dell.com*

Source	Health Level 7
Name	HL7 Version 2 Messaging Standard
Date	2011
URL	*www.hl7.org/implement/standards/product_brief.cfm?product_id=185*
Domain	Healthcare
Scope	Communications/Networking, Data and Information Management
Comments	Electronic data exchange between systems in the clinical domain. The standard is designed to support a central patient care system as well as a more distributed environment where data resides in departmental systems.
Submitter	Erin Bournival (Dell Technologies), *erin.bournival@dell.com*

Source	ISO/TC 159/SC 3 (Anthropometry and biomechanics)
Name	ISO/IEEE 11073: Health informatics – Point-of-care medical device communication
Date	2014
URLs	• *https://en.wikipedia.org/wiki/ISO/IEEE_11073_Personal_Health_Data_(PHD)_Standards* • *https://www.techstreet.com/ieee/searches/34401518* • *https://11073.org/*
Domain	Healthcare
Scope	System Architecture
Description	Personal Health Device (PHD) standards are a group of standards addressing the interoperability of personal health devices (PHDs) such as weighing scales, blood pressure monitors, blood glucose monitors and the like. ISO/IEEE 11073 is a multi-part standard whose core, non-device-specific elements include, among others: • ISO/IEEE 11073-00103:2012 (Overview) • ISO/IEEE 11073-10101:2004 (Nomenclature) • ISO/IEEE 11073-10201:2018 (Domain information model) • ISO/IEEE 11073-10206 (Abstract information content model) • ISO/IEEE 11073-20101:2004 (Application Profile – Base Standard) • ISO/IEEE 11073-20601:2010 (Application profile – Optimized exchange protocol) • ISO/IEEE 11073-20702:2016 (Medical Devices Communication Profile for Web Services)
Comments	Under development
Submitter	Erin Bournival (Dell Technologies), *erin.bournival@dell.com*

Source	IHE International
Name	Patient Care Device (PCD) Profiles
Date	Varies by profile from 2009 to 2016 (see details at link below)
URL	*https://wiki.ihe.net/index.php?title=PCD_Profiles*
Domain	Healthcare
Scope	System Architecture, Communications/Networking, Data and Information Management
Description	The IHE PCD develops standards-based interoperability profiles that address specific integration problems within the domain charter.
Comments	The 14 profiles listed below have not been reviewed individually to ascertain their relevance to Industry IoT or their current status. • ACM (Alert Communication Management) • DEC (Device Enterprise Communication) • MEMDMC (Device Management Communication) • DPI (Device Point of Care Integration) / RDC (Rapid Device Configuration) • IDCO (Implantable Device Cardiac Observations) • IPEC (Infusion Pump Event Communication) • MEMLS (Location Services) • MEM (Medical Equipment Management) • PIV (Point of Care Infusion Verification) • PCIM (Point of Care Identity Management) • Pulse Oximetry Integration with Clinical Applications • RDQ (Retrospective Data Query) • RTM (Rosetta Terminology Mapping) • WCM (Waveform Communication Module)
Submitter	Erin Bournival (Dell Technologies), *erin.bournival@dell.com*

2.4 ENERGY

Source	IEEE
Name	IEEE 2030.5 Smart Energy Profile Application Protocol
Date	2018
URL	*https://standards.ieee.org/ieee/2030.5/5897/*
Domain	Energy (Electricity)
Scope	Communications/Networking
Description	IEEE 2030.5 is a standard for communications between the smart grid and consumers. The standard is built using IoT concepts and gives consumers a variety of means to manage their energy usage and generation. Information exchanged using the standard includes pricing, demand response, and energy usage, enabling the integration of devices such as smart thermostats, meters, plug-in electric vehicles, smart inverters, and smart appliances. IEEE 2030.5 further defines a framework to support these applications to enable a secure, interoperable, and plug-and-play ecosystem of smart grid consumer devices. IEEE 2030.5 has been recommended as the default protocol for smart inverter communications for California's Rule 21.
Submitter	Eddie Lee (Moxa Software), *eddie.lee@moxa.com*

Source	EEBUS Initiative
Name	SHIP (Smart Home IP) and SPINE (Smart Premises Interoperable Neutral Message Exchange)
Date	2016
URL	*www.eebus.org/media-downloads/#specifications*
Domain	Energy (Electricity)
Scope	System Architecture, Communications/Networking, Data and Information Management
Description	EEBUS specifies the language of energy using the SHIP, SPINE and Use Case specifications. Bosch Software Innovations and KEO Connectivity provide a simple implementation of the EEBUS interface via their software products for EEBUS integration.
Comments	Specific to electricity management in smart homes. Includes an architecture, communication protocol, and datagram format.
Submitter	Claude Baudoin (cébé IT & Knowledge Mgmt.), *cbaudoin@cebe-itkm.com*

Source	European Committee for Electrotechnical Standardization (CENELEC)
Name	KNX, also known as EN 50090 and ISO 14543-3 (multiple subparts)
Date	2006
URLs	• *www.iso.org/committee/45270/x/catalogue/p/1/u/0/w/0/d/0* • *https://en.wikipedia.org/wiki/KNX_(standard)* (The ISO 14543 catalog is hard to navigate and seems incomplete, showing parts 14543-3-1 through 14543-3-7, then 14543-3-10 and 14543-3-11)
Domain	Energy (Electricity), Smart Cities, Smart homes, Building Automation
Scope	System Architecture, Communications/Networking, Data and Information Management
Description	An open standard (see EN 50090, ISO/IEC 14543) for commercial and domestic building automation. KNX evolved from three earlier standards: the European Home Systems Protocol (EHS), BatiBUS, and the European Installation Bus (EIB or Instabus). On this network, the devices form distributed applications and tight interaction is possible. This is implemented via interworking models with standardized datapoint types and objects, modelling logical device channels.
Comments	KNX is originally an abbreviation for the word Konnex; the KNX Association is based in the Dutch-speaking part of Belgium.
Documents	See the history of KNX, EN 50090 and ISO 14543 at *www.domo-energie.com/usr_file/Pdf/knx_is_international_standard.pdf*
Submitter	Claude Baudoin (cébé IT & Knowledge Mgmt.), *cbaudoin@cebe-itkm.com*

Source	ISO TC 205 (Building Environment Design)
Name	ISO 17800:2017 Facility smart grid information model
Date	2017
URL	*https://www.iso.org/standard/71547.html*
Domain	Energy (Electricity)
Scope	Data and Information Management, Interoperability
Description	Provides the basis for common information exchange between control systems and end use devices found in single- and multi-family homes, commercial and institutional buildings, and industrial facilities that is independent of the communication protocol in use. It provides a common basis for electrical energy consumers to describe, manage, and communicate about electrical energy consumption and forecasts.
Submitter	European Union Observatory on Standards (listed in Digital Twin Landscape)

Source	ISO/IEC JTC 1/SC 27
Name	ISO/IEC 27019:2017 Information technology – Security techniques – Information security controls for the energy utility industry
Date	2017
URL	*https://www.iso.org/standard/68091.html*
Domain	Energy (Electricity)
Scope	Security and Trustworthiness
Description	Provides guidance based on ISO/IEC 27002:2013 (information security controls) applied to process control systems used by the energy utility industry for controlling and monitoring the production or generation, transmission, storage and distribution of electric power, gas, oil and heat, and for the control of associated supporting processes.
Comments	ISO/IEC 27002 has been revised in 2022; it is not known at this time whether ISO/IEC 27019 requires revisions as a consequence. The relevance to IoT comes from the mention, in the description of the standard, of "digital controllers and automation components such as control and field devices or Programmable Logic Controllers (PLCs), including digital sensor and actuator elements."
Submitter	European Union Observatory on Standards (listed in Digital Twin Landscape)

3 DOMAIN-SPECIFIC SUPPORTING STANDARDS

The standards in this section are generally used in the technology stack that supports IIoT systems in a particular vertical domain but are not specific to IIoT themselves.

3.1 MANUFACTURING

Note that this section does not include legacy standards for Supervisory Control and Data Acquisition (SCADA).

Source	International Society of Automation (ISA)
Name	PackML (formally ISA TR88.00.02)
Date	2009
URL	*https://www.omac.org/packml*
Domain	Manufacturing
Scope	Data Representations
Description	The primary objective of PackML is to bring a common "look and feel" and operational consistency to all machines that make up a Packing Line. PackML provides: • Standard defined machine states and operational flow • Overall Equipment Effectiveness (OEE) data • Root Cause Analysis (RCA) data • Flexible recipe schemes and common SCADA or MES (Manufacturing Execution System) inputs
Submitter	Tom Doney (AdvME LLC) via Daniel Young (Toshiba), *daniel1.young@toshiba.com*

Source	IEC TC 65 (Automation)
Name	IEC 62714 AutomationML -- Engineering data exchange format for use in industrial automation systems engineering
Date	2018
URL	*https://www.automationml.org/* Part 1: *https://webstore.iec.ch/publication/63059*
Domain	Manufacturing
Scope	System Architecture, Data and Information Management
Description	AutomationML (Automation Markup Language) is an open, neutral XML-based data format for the storage and exchange of plant engineering information. The goal of AutomationML is to interconnect the heterogeneous landscape of modern engineering tools in their different disciplines (e.g., mechanical plant engineering, electrical design, process engineering, process control engineering, HMI development, PLC programming, robot programming, etc.).
Comments	Well adopted in engineering tools for discrete manufacturing.
Submitters	Erich Barnstedt (Microsoft), *erichb@microsoft.com* European Union Observatory on Standards (listed in Digital Twin Landscape)

Source	IEC TC 65 (Automation)
Name	IEC 62890:2020 – Industrial process measurement, control, and automation – Life cycle management for systems and components
Date	2020
URL	*https://webstore.iec.ch/publication/30583*
Domain	Manufacturing
Scope	System Architecture
Description	Establishes basic principles for life cycle management of systems and components used for industrial process measurement, control, and automation. This standard provides definitions and reference models related to the life cycle of a product type and the lifetime of a product instance.
Submitter	European Union Observatory on Standards (listed in Digital Twin Landscape)

Source	IEC TC 65 (Automation)
Name	IEC 62264-3:2016 – Enterprise control system integration – Part 3: Activity models of manufacturing operations management
Date	2016
URL	*https://webstore.iec.ch/publication/33511*
Domain	Manufacturing
Scope	Enterprise Systems Integration
Description	Defines activity models of manufacturing operations management that enable enterprise system to control system integration. The activities defined in this document are consistent with the object models definitions given in IEC 62264-1.
Submitter	European Union Observatory on Standards (listed in Digital Twin Landscape)

Source	IEC
Name	IEC 61512-2:2011 – Batch control – Part 2: Data structures and guidelines for languages
Date	2001
URL	*https://webstore.iec.ch/publication/5529*
Domain	Manufacturing
Scope	Data and Information Management
Description	This part of this standard on batch control defines data models that describe batch control as applied in the process industries, data structures for facilitating communications within and between batch control implementations and language guidelines for representing recipes.
Submitter	European Union Observatory on Standards (listed in Digital Twin Landscape)

Source	IEC TC 65 (Automation)
Name	IEC PAS 63088 – Smart Manufacturing – Reference Architecture Model Industry 4.0 (RAMI4.0)
Date	March 2017
URL	*https://webstore.iec.ch/publication/30082*
Domain	Manufacturing
Scope	Reference Architecture
Description	Describes a reference architecture model in the form of a cubic layer model, which shows technical objects (assets) in the form of layers, and allows them to be described, tracked over their entire lifetime (or vita) and assigned to technical and/or organizational hierarchies. It also describes the structure and function of Industry 4.0 components as essential parts of the virtual representation of assets.
Submitter	European Union Observatory on Standards (listed in Digital Twin Landscape)

3.2 HEALTHCARE

Note that certain overarching standards or regulations, such as the Health Insurance Portability and Accountability Act (HIPAA) impact the handling of patient information collected through IoT sensors and systems. However, those are not IoT-specific and are not listed below.

Source	Health Level 7 (HL7)
Name	Fast Healthcare Interoperability Resources (FHIR) v4.0.1
Date	2019
URL	*https://hl7.org/fhir/*
Domain	Healthcare
Scope	Data and Information Management, Interoperability
Description	FHIR is a standard describing data formats and elements and an application programming interface for exchanging electronic health records.
Comments	Electronic health record representation and access, downstream from any IoT-based data acquisition. Well adopted throughout the industry.
Submitter	Erin Bournival (Dell Technologies), *erin.bournival@dell.com*

Source	European Telecommunications Standards Institute (ETSI)
Name	ETSI Technical Report 102 764 V1.1.1 – eHEALTH Architecture – Analysis of user service models, technologies and applications supporting eHealth
Date	2009
URL	*www.etsi.org/deliver/etsi_tr/102700_102799/102764/01.01.01_60/tr_102764v010101p.pdf*
Domain	Healthcare
Scope	Enterprise/Systems Integration, Data and Information Management, Communications and Networking, others
Description	eHealth includes the application of ICT (information and communications technologies) across the whole range of functions that affect the health sector.
Comments	Refers to multiple standards and technical reports
Submitter	Erin Bournival (Dell Technologies), *erin.bournival@dell.com*

3.3 ENERGY

Source	European Committee for Electrotechnical Standardization (CENELEC)
Name	BS EN 16212:2012 Calculations of savings and energy efficiency – Top-down methods (descending) and bottom-up (ascending)
Date	2012e
URL	ISBN: 978 0 580 78442 2 • *https://www.en-standard.eu/bs-en-16212-2012-energy-efficiency-and-savings-calculation-top-down-and-bottom-up-methods/* • *https://standards.iteh.ai/catalog/standards/clc/092d4634-36fd-4c0e-ae76-f4ba9a6d1e33/en-16212-2012*
Domain	Energy (Electricity)
Scope	Guidelines
Description	The standard is meant to be used for ex-post evaluations of realized savings as well as ex-ante evaluations of expected savings. This European Standard provides saving calculations for any period chosen.
Comments	This standard is relevant to Industrial IoT to the extent that IoT sensors may provide some of the information needed to perform the calculations.
Submitter	Alan McGibney (MTU), *alan.mcgibney@mtu.ie*

Source	European Telecommunications Standards Institute (ETSI)
Name	ETSI TS 103 410-1 V1.1.2 (2020-05): SmartM2M – Extension to SAREF – Part 1: Energy Domain
Date	2020
URL	*https://saref.etsi.org/core/* *https://www.etsi.org/deliver/etsi_ts/103400_103499/10341001/01.01.02_60/ts_10341001v010102p.pdf*
Domain	Energy (Electricity)
Scope	Data Representation
Description	This standard represents energy systems and data using a standard ontology for smart IIoT applications. It is meant to enable the (currently missing) interoperability among various proprietary solutions.
Comments	SAREF is the Smart Applications REFerence) ontology from ETSI)
Submitter	Alan McGibney (MTU), *alan.mcgibney@mtu.ie*

Source	ISO
Name	ISO 50001:2018 – Energy management systems—Requirements with guidance for use
Date	2018
URL	*https://www.iso.org/iso-50001-energy-management.html*
Domain	Energy (Electricity)
Scope	Guidelines
Description	"Provides a practical way to improve energy use, through the development of an energy management system (EnMS)."
Comments	IIoT is key to provide performance data in a continuous manner. Tools that support implementation of ISO 50001 can leverage IIoT to monitor energy performance indicators. Related standards: • EN ISO 50002:2014 (Energy audits—Requirements with guidance for use) • EN ISO 14001:2004 (Environmental management systems - requirements and guide for use)
Submitter	Alan McGibney (MTU), *alan.mcgibney@mtu.ie*

Source	IEC TC 57 (Power Systems)
Name	IEC 61850:2022 SER – Communication networks and systems for power utility automation (All parts)
Date	2022
URL	*https://webstore.iec.ch/publication/6028* For Part 1-2, see *https://webstore.iec.ch/publication/59652*
Domain	Energy (Electricity)
Scope	Communications/Networking, Guidelines
Description	Defines communication protocols for intelligent electronic devices at electrical substations. Part 1-2 (Guideline on extending IEC 61850) is Intended for any users but primarily for standardization bodies that are considering using IEC 61850 as a base standard within the scope of their work and are willing to extend it as allowed by the IEC 61850 standards.
Submitter	European Union Observatory on Standards (listed in Digital Twin Landscape)

Source	Energistics
Name	WITSML (Well-site Information Transfer Standard Markup Language) 2.0
Date	2016
URL	*http://docs.energistics.org/WITSML/WITSML_TOPICS/WITSML-000-000-titlepage.html*
Domain	Energy (Oil & Gas)
Scope	Data representation
Description	WITSML is the upstream oil and gas data-transfer standard for specifying and exchanging data for wells and well-related operations and objects, such as drilling, logging, and mud logging.
Submitter	Claude Baudoin (cébé IT & Knowledge Mgmt.), *cbaudoin@cebe-itkm.com*

Source	Energistics
Name	Energistics Transfer Protocol (ETP) v1.2
Date	2021
URL	*https://www.energistics.org/introduction-to-etp-v1-2/*
Domain	Energy (Oil & Gas)
Scope	Data and Information Management
Description	The ETP data exchange specification enables efficient transfer of data between applications. The initial use case is for real-time data; however, it is anticipated that ETP will be expanded to include functionality for historical data queries. ETP has been specifically envisioned and designed to meet the unique needs of the upstream oil and gas industry and especially to facilitate the exchange of data across the Energistics family of data standards, which includes WITSML, PRODML and RESQML.
Comments	Incompletely adopted. Energistics chose to develop an entire standard from scratch instead of layering some industry-specific capabilities on top of OPC-UA or DDS.
Submitter	Claude Baudoin (cébé IT & Knowledge Mgmt.), *cbaudoin@cebe-itkm.com*

Source	ISO TC 184 (Automation Systems and Integration)
Name	ISO 18101-1:2019 Oil and Gas Interoperability Technical Specification
Date	2019
URL	*https://www.iso.org/standard/68521.html*
Domain	Energy (Oil & Gas)
Scope	System Architecture
Description	Provides requirements, specifications, and guidance for an architecture of a supplier-neutral industrial digital ecosystem. It includes a standardized connectivity and services architecture, and a standardized use case architecture with methods to specify atomically re-usable scenarios and events, which can be used to specify the characteristics of standardized industry use cases.
Submitter	European Union Observatory on Standards (listed in Digital Twin Landscape)

4 CROSS-INDUSTRY IOT SUPPORTING STANDARDS

The standards in this section are generally used in the technology stack that supports IIoT systems across multiple specific (possibly all) vertical industry domains but are not specific to IIoT themselves.

Source	ISO/IEC JTC 1/SC 41
Name	ISO/IEC 30141 IoT Reference Architecture
Date	2018
URL	*www.iec.ch/dyn/www/f?p=103:38:607668603953669::::FSP_ORG_ID,FSP_APEX_PAGE,FSP_PROJECT_ID:20486,23,104064*
Scope	System Architecture, Enterprise/Systems Integration, Security and Trustworthiness
Description	IoT Reference Architecture
Comments	Relates to/competes with the IIC Reference Architecture (IIRA)
Submitter	Erin Bournival (Dell Technologies), *erin.bournival@dell.com*

Source	International Society of Automation (ISA)/IEC
Name	ISA-62443: Security for Industrial Automation and Control Systems (multiple parts)
Dates	2007 to 2020
URL	*https://www.isa.org/standards-and-publications/isa-standards/isa-iec-62443-series-of-standards*
Scope	Security and Trustworthiness
Description	Requirements and processes for implementing and maintaining electronically secure industrial automation and control systems (IACS). The ISA/IEC standards set cybersecurity benchmarks in all industry sectors that use IACS, including building automation, electric power generation and distribution, medical devices, transportation, and process industries such as chemicals and oil and gas.
Documents	Also see "Quick start guide: An overview of the ISA/IEC 62443 Standards" (*https://gca.isa.org/isagca-quick-start-guide-62443-standards*) published by the ISA Global Security Alliance.
Submitter	European Union Observatory on Standards (listed in Digital Twin Landscape)

Source	GS1
Name	EPC Information Services (EPCIS) Standard, v1.2
Date	2016
URL	*www.gs1.org/standards/epcis*
Scope	Data and Information Management
Description	Enable trading partners to share information about the physical movement and status of products as they travel throughout the supply chain.
Comments	Well adopted throughout the industry. Tracking the movement of goods (events through the supply chain) could be improved by IoT but this is not directly an IoT standard.

Source	European Telecommunications Standards Institute (ETSI)
Name	ETSI TR 103 507 V1.1.1: SAREF extension investigation – Requirements for industry and manufacturing domains
Date	October 2018
URL	*http://webapp.etsi.org/workprogram/Report_WorkItem.asp?WKI_ID=51400*
Scope	Information Modeling
Description	Requirements for an initial semantic model for industry and manufacturing domains. Developed in close collaboration with AIOTI, the H2020 Large Scale Pilots and with ETSI activities in this domain. Further extensions are envisaged in the future to cover entirely the industry and manufacturing domains.
Comments	SAREF is the Smart Applications REFerence) ontology from ETSI)
Submitter	European Union Observatory on Standards (listed in Digital Twin Landscape)

Source	European Telecommunications Standards Institute (ETSI)
Name	ETSI TR 103 778 V1.1.1: Use cases for cross-domain data usability of IoT devices
Date	Dec. 2021
URL	*www.etsi.org/deliver/etsi_tr/103700_103799/103778/01.01.01_60/tr_103778v010101p.pdf*
Scope	Data and Information Management
Description	Due to the growing use of AI models in standards, ETSI Technical Bodies have decided to investigate means to assess the "quality" and usability of datasets needed to train and also to test the AI capabilities referenced by new standards, which is one of the motivations for this work. IoT devices and platforms also provide data that are used directly by human and very often non-technical users. Trust in the IoT system can be ensured only if these data bring in a real added-value and are delivered in a non-ambiguous manner to these users.
Submitter	European Union Observatory on Standards (listed in Digital Twin Landscape)

5 RECOMMENDATIONS AND NEXT STEPS

We have enumerated several standards that are eligible for use within four vertical industries. Readers of this paper are encouraged to identify matches between the content in this document and the work they're performing, to whenever possible leverage existing standards and avoid "reinventing the wheel." We recommend that you:

- review the use of standards in your own organization,
- provide feedback on your own initiatives and experiences in the use and development of standards to the IIC Standards Task Group,
- 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.

This landscape report is a living document. Most IoT-related standards are recent, and several more are under development. The standards mentioned in this document are highly likely to be revised over the next few years. Readers should send new or revised entries to *iic-standards@iiconsortium.org* for inclusion in subsequent versions.

Annex A TEMPLATE FOR NEW ENTRIES

This template is provided for the convenience of reviewers of this document to facilitate the submission of additional entries with all appropriate descriptors.

Source	Name of the SDO and/or technical committee
Name	
Date	
URL	Pointer to the actual standard if available
Domain	One or more of: Manufacturing, Transportation, Healthcare, Energy (additional domains may be added later)
Scope	Enter in this field one of the values specified in Section 1.2 on page 6
Description	May be cut-and-pasted from the standard's description page, or a summary created by the submitter
Comments	
Documents	Reference to additional documents besides the one whose URL is given above
Submitter	Name, affiliation, and e-mail address to facilitate follow-up

AUTHORS & LEGAL NOTICE

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