Introduction to the proposed new multipart standard

Industrial automation systems and integration – Ontology-based Interoperability

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Contents

1 Purpose of this document

This document is an attachment to ISO Form4 NEW WORK ITEM PROPOSAL (NP) sent to ISO/TC 184/SC 4 for a new multipart standard called *Industrial automation systems and integration – Ontology-based Interoperability.*

It's purpose is to provide more information about the proposed multipart standard.

2 Motivation

The objective of the new standard is to facilitate digitalization across various industries and domains by establishing a common digital vocabulary that enables the utilization of reference data within diverse standards, encompassing both ISO/TC 184/SC 4 and other standardization organizations.

The objective requires a commitment to compatibility across all parts of the standard: The digitalized requirements of each part must be expressed in a single, shared language, and the ability to verify consistency as the standard evolves is crucial. The Industrial Data Ontology (IDO; see section 4) serves a foundational role in the new standard to meet these requirements, as a basic language with which specialized modules can be expressed, and with the ability to verify consistency at scale, by means of OWL 2 DL reasoning.

Each part of the new standard will therefore utilize IDO *models* to represent knowledge, structured as OWL 2 DL compliant ontologies.

The volume and complexity of industrial data calls for support from automated systems. The importance of consistency management in industry is best justified by pointing to a selection of use cases:

- The engineering contractor Aibel in Norway employs reasoning on a large collection of IDO-based ontologies to ensure consistency and standards compliance in their master data management solution, where *material* master records are OWL classes. Reasoning is performed to avoid creation of duplicate records [9].
- A study on Failure Mode and Effects Analysis (FMEA) demonstrates how reasoning with IDO-based ontologies can be used to identify the impact of failures on system function [10].
- TotalEnergies in France considers IDO to be a suitable candidate for their mission to improve the integration of digital technical data and structuring models [11].
- Siemens Energy uses IDO (currently ISO 15926-14:2020, migration to IDO will be targeted as soon as it is available) as the top-level ontology in their ontology stack. The knowledge management tools built by Siemens Energy implement modeling patterns based on IDO [12].
- Grundfos in Denmark is building a large product model using IDO, where the knowledge of multiple engineers and source data from engineering tools is automatically combined and enriched into an OWL ontology. Grundfos relies on validation using OWL reasoning to ensure scalability and maintainability of a big enterprise ontology with many contributors. The simplicity of the IDO ontology and the availability of a community of IDO users is appreciated.

3 Scope of *Industrial automation systems and integration – Ontology-based Interoperability*

At this early stage, we are clear that the purpose of the new standard is to serve the representation and integration of industrial data and industry standards. This means, to build vocabularies and asset models, and to manage asset models which employ reference data libraries. The new standard is intended for use in all life cycle phases of industrial assets and processes.

We foresee that future parts of the standard will be introduced to support the requirements of specific industries, including, but not limited to the following four types of standard content:

1. Methodology and implementation guides

Best practice modelling for various industrial disciplines (e.g., the CIM [15], BIM/IFC [16] communities have shown interest in IDO).

Work is in progress for the Facility Asset Information Modelling Framework (IMF). IMF is an engineering-friendly block language for asset modelling based on configuration and instantiation of types, systems-of-systems thinking, and aspects, where the concept of aspect is based on and extends ISO/IEC 81346-1. IMF builds upon IDO in two ways. First, it is designed to use reference data compliant with IDO. Second, IMF models are interpreted using IDO. The effect is that integrity checking of IMF models is completely achieved by means of reasoning over IDO ontologies and models. The IMF project is currently implemented in Equinor, AkerBP, Aker Solution and Aibel, and developed as an industry wide collaboration including the same stakeholders that stand behind and contribute to the development of IDO. DNV currently develops a Recommended Practice for IMF that will be published in 2023, and Equinor plans to release a specification of IMF in the fall of 2023. These documents will form the basis for a new part of the new standard.

Reasoning methods complementary to OWL DL inference, including SHACL[1] and various logic programming languages.

2. Integration and application of existing standards

[1] For the W3C Shapes Constraint Language (SHACL), see https://www.w3.org/TR/shacl/.

Detailed specifications for integration and re-use of existing reference data libraries. Examples include ISO 10303, IEC CDD (IEC 61987), IEC 61360-1, eCl@ss, and Norwegian NORSOK standards.

Work is in progress with DISC and PCA for adapting ISO 15926 Part 4 to IDO.

3. New domain ontologies and vocabularies (Reference data)

Ontologies for project control such as scheduling, cost, estimates, weight and other information types for project control to enable interoperability, digital twin capabilities and artificial intelligence for project control. Ontology for scheduling, including time, is under development and will be proposed later in 2023.

4. Libraries of modelling patterns (templates)

Work in progress: IDO template library, published as a PCA on-line service

Discipline specific template libraries, supporting both new ontologies based on IDO and existing reference data sources adapted to IDO as under Point 2 above.

4 The Industrial Data Ontology

The Industrial Data Ontology (IDO) is proposed as the initial part of the new standard, with the full name *Industrial automation systems and integration – Ontology Based Interoperability – Part [TBA] Industrial* Data Ontology. This ontology is intended for use in all life cycle phases of industrial assets and processes, to build vocabularies and manage asset models that employ Reference Data Libraries (RDLs).

IDO is a W3C OWL 2 ontology [1,2] (2012). OWL 2 provides a language suitable for reliable, large-scale industrial ontologies. Applications may be implemented using the Semantic Web ecosystem of methods and software technology, based on W3C standards.

IDO originated in an adaptation of the ISO 15926-2:2003 data model ("Part 2") made to facilitate Semantic Web development. IDO is intentionally restricted in expressive power to secure that its applications can exploit automated reasoning according to OWL 2 *Direct Semantics* [3] ("OWL 2 DL").

IDO retains its basis in the Part 2 data model and can make use of the major efforts and knowledge of the POSC Caesar Association (PCA) community. The PCA community has played a leading role in the development of ISO 15926 and compliant RDLs.

IDO also draws on Basic Formal Ontology (BFO) [13] for improvements affecting function, quantification, and more.

IDO facilitates the use of RDLs originating outside of ISO 15926. For the current effort in alignment of ISO/TC 184/SC 4 reference data standards, IDO will be suitable as a "top-level" ontology for the "Core terminology for industrial data" [14] which is a terminology for industrial data that defines generic terms for things that exist in more than one industrial domain. It is developed by ISO/TC 184/ SC 4 and is equally applicable to all ISO/TC 184/SC 4 standards. In addition, IDO will also include mappings to widely used ontologies, including Semantic Sensor Networks, the Time Ontology in OWL, and GeoSPARQL,[2] and provide detailed modelling examples for selected industrial use cases.

4.1 Background on IDO – why a new standard is needed

The previous version of IDO was known under the name ISO/DTR 15926-14 *Data model adapted for OWL 2 Direct Semantics* (or simply "Part 14"). Designed to allow efficient use of automated reasoning, and with an openness to best practice modelling in the wider applied ontology

[2] See, resp., https://www.w3.org/TR/vocab-ssn/, https://www.ogc.org/standard/geosparql/, and https://www.w3.org/TR/owl-time/.

community, the ontology was initially developed by DNV as part of the IOHN joint industry project (2008—2012).[3] It was later refined and documented by the EU-funded project Optique (2012—2016).[4] The ontology has been successfully applied in several large industrial implementations, including by Aibel, Aker Solutions, and DNV (cf. Section 4 below).

The proposal for a Part 14 of ISO 15926 was presented at the ISO/TC 184/SC4 meeting in Oslo, May 2017. It was well received by the Oil and Gas industry, and it was recommended to publish the proposal as an ISO Technical Report (TR). The proposal also generated significant interest in the Process Plant, Aerospace, Defense and Automotive industries.

PCA developed an ISO New Project (NP) proposal with the necessary attachments. This proposal was approved July 30th, 2018. All comments from the NP ballot were resolved, and an improved version, ISO/DTR 15926-14, was issued for ISO Technical Report ballot. The proposal was approved with 11 Approval, 0 Disapproval and 5 Abstention votes.

In standard terms, a TR is 'informative' and not 'normative'. It is not possible to refer normatively to a TR from other ISO and IEC standards, and a TR may not be used as a top-level ontology for other ontologies in ISO and IEC standards.

Several existing industry projects and initiatives are based on Part 14. To be able to standardize these, on the request of the user community, a Working Draft (WD) proposal for an "ISO/IS Industrial top-level ontology" was prepared by the READI joint industry project in 2020.[5] This WD was submitted as a New Project (NP) proposal in November 2022 and presented to ISO/TC 184/SC 4 in Hamamatsu the same month. ISO/TC 184/SC 4/WG 3 did not reach consensus on the NP, and ISO/TC 184/SC 4 initiated a study group of ISO 15926 and OWL experts which reported to PPC in February 2023. The study group evaluated the suitability of the proposed part for ISO 15926, including semantic commitments and whether the existing ISO/TS 15926-12 would suffice for reasoning on industrial data with the same results as for the NP. The study concluded that Part 14 was not compatible with fundamental assumptions, in particular that of four-dimensionalism, of ISO 15926. Because of this, the NP was withdrawn. At the same time, the ISO 15926-14 DTR (Project Id. 75949) was found to be no longer useful, and it was also withdrawn in March 2023.

4.2 Current contributors to IDO development

4.2.1 The "IDO consortium"

The WD, now submitted to SC4, has been developed by a consortium of parties representing different countries, industries, and academic institutions. Currently, the consortium is governed by an interim steering committee with the following organizations represented:

Role	Organization	Industry/Country	Type of company
Project owner	PCA	Energy/Norway	Association developing and promoting use of standards
Member	TotalEnergies	Energy/France	Owner/Operator
Member	Equinor	Energy/Norway	Owner/Operator
Member	Aker BP	Energy/Norway	Owner/Operator
Member	Siemens	Several/Germany	Manufacturing
Member	Grundfos	Several/Denmark	Pump manufacturing

[3] For information on the Integrated Operations in the High North project (IOHN, 2008—2012), see https://en.wikipedia.org/wiki/Integrated_Operations_in_the_High_North.
[4] For information on the Optique project (2012—2016), see https://cordis.europa.eu/project/id/318338.
[5] For information on the REquirement Asset Digital Lifecycle Information project (READI, 2018—2022), see https://readi-jip.org.

Role	Organization	Industry/Country	Type of company
Member	Aibel	Energy/Norway	EPC
Member	Aker Solutions	Energy/Norway	EPC
Member	SEIIA	Several/Sweden	Association promoting interoperability in Sweden
Member	Standards Norway	Several/Norway	Standardization
Observer	University of Western Australia	R&D/Australia	University
Observer	University of South Australia	R&D/Australia	University
Observer	University of Oslo	R&D/Norway	University
Consultant for PCA	DNV	Several/Norway	Classification society

In addition, IOGP, represented by CFHIOS, has been invited in to the ISC as an observer.

4.2.2 Digitalisation, Industrialisation, Standardisation, Collaboration, a "catalyst" to speed up development and industry application of IDO

The companies AkerBP, Equinor, Aibel and Aker Solutions have together established Digitalisation, Industrialisation, Standardisation, Collaboration (DISC), a digital industry collaboration initiative between stakeholders on the Norwegian Continental Shelf.

DISC shall establish a common platform for digitalization to facilitate a seamless exchange of information through:

- Development of digital information models based on common and shared libraries of object models, denoted "IMF types"
- Promotion of an open industrial vocabulary, i.e., Reference Data Libraries (RDLs), built according to IDO
- Publication of the RDLs through the POSC Caesar Association (PCA)

Currently, DISC is working on applying reference data based on IDO for the following industrial use cases and practical applications:

- Single Line diagram
- Electro load lists
- Process & Information Diagram (P&ID)
- Digital datasheets
- Compliance verifications
- Maintenance and Integrity Management
- Work planning and order (WO)
- Cyber security assessment

Significant contributions have been seen until now in the development of IDO, and one can expect more going forward. Hence, DISC can be seen as a catalyst and test bed to speed up already started digital projects applying IDO and IMF in full scale industrial development projects.

4.2.3 Other collaboration (current and future)

Development and industrial uptake of IDO has been done in collaboration with international R&D projects and standardization associations. It is expected that this also be the case in the future. Some of the projects and associations are mentioned below.

4.2.3.1 *Arrowhead-fPVN*

The Arrowhead flexible Production Value Network (fPVN) is an EU-funded project which will commence June 1st, 2023.

The project will provide autonomous and evolvable interoperability of information through machine-interpretable content for fPVN stakeholders. The resulting technology is projected to substantially impact manufacturing productivity and flexibility.

Autonomous and evolvable interoperability will be achieved through common project technology based on three pillars:

1. Microservices paradigm,
2. Utilization of major industrially accepted data models,
3. Automatic translation between the data models.

The common technology will be validated and verified in 11 use cases covering the production value networks in different industrial production domains.

The results are expected to considerably impact the efficiency of both local and global production value networks thanks to substantial cost and time reduction for setting up, operating, and managing the interactions within production value networks.

4.2.3.2 *OntoCommons*

OntoCommons is an H2020 CSA project dedicated to the standardization of data documentation across all domains related to materials and manufacturing.[6]

OntoCommons lays the foundation for interoperable, harmonised and standardised data documentation through ontologies, facilitating data sharing and pushing data-driven innovation, to bring out a truly Digital Single Market and new business models for European industry, exploit the opportunities of digitalisation and address sustainability challenges.

By developing the Ontology Commons EcoSystem (OCES) - a set of ontologies and tools that follows specific standardization rules - and provide a sustainable approach, making the data FAIR (Findable, Accessible, Interoperable and Reusable). Moreover, the OCES implements practical and user-friendly mechanisms of intra- and cross-domain interoperability focusing on materials and manufacturing sectors.

This will be achieved by coordinating a wide range of EU stakeholders and with the support of Demonstration Cases with strong industrial involvement, covering a wide range of NMBP (Nanotechnologies, Advanced Materials, Biotechnology, and Advanced Manufacturing and Processing) application domains.

Several of the partners in the community developing IDO are members in OntoCommons, and PCA and OntoCommons have agreed on a Memorandum of Understanding (MOU) for collaboration.

4.2.3.3 *Industrial Ontologies Foundry*

The Industrial Ontologies Foundry (IOF) is a unit of the Open Applications Group (OAGi).[7] The IOF is creating a suite of ontologies for digital manufacturing specifically focusing on the types of machines (e.g., milling machines) that make industrial products and parts, and on modelling the data that needs to be exchanged about the product specifications and the production process. The IOF ontologies currently consists of a mid-level ontology released as “Core" and two provisional modular ontologies for supply chain and maintenance. IOF has also pursued use of temporalized relations, a variant of the Basic Formal Ontology 2.0 to which IOF has aligned. IDO has not taken this

[6] https://ontocommons.eu/
[7] https://industrialontologies.org/

path, allowing industry users to choose which option will work for them, as both support reasoning.[8]

Several contributors to the IDO ontology are also actively involved in the IOF ontology development. This is because their work covers both manufacturing (IOF) and the process industries (IDO) and the option to use temporalized relations (IOF) or not (IDO) depending on their use case. Thus, developments in these two communities are complementary.

To the best of the authors' knowledge, at the time of writing there is no active initiative to integrate the IOF ontologies into the ISO standardisation process and there are no publicly available demonstrations of industry use of the IOF ontologies.

4.2.3.4 *Industrial Digital Twin Association*

The Industrial Digital Twin Association (IDTA)[9] is a member organization responsible for the development, maintenance, and propagation of the 'Industrie 4.0' standards, notably the Asset Administration Shell. Equinor and the University of Oslo are both members of the association and participate in working groups of relevance to the DISC project and other initiatives. We see the IDTA as being a valuable collaboration partner in using the IDO to define semantics of items in Asset Administration Shell models and OPC data models.

IDTA is now staring up a new workstream called "IDTA Workstream Ontology". IDO representatives are invited in to collaborate in this workstream.

4.2.3.5 *Data Exchange in the Process Industry*

Data Exchange in the Process Industry (DEXPI)[10] is a voluntary organization, now being reorganized as a membership organization, with responsibility for developing standards for the modelling and interchange of process engineering design data. The current version of the DEXPI project provides a model of the information shown on P&IDs. A new version of the standard, DEXPI+, will be extended to model early-phase process design, as expressed in Block Diagrams and Process Flow Diagrams. The DEXPI data model, especially in the new standard, is compatible with IMF modelling and can use IDO semantic definitions.

5 Contact information

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[8] See Chris Mungall, "A critique of temporalized relations", available at https://raw.githubusercontent.com/cmungall/temporalized-relations-critique/master/trc.pdf.
[9] https://industrialdigitaltwin.org/en/
[10] https://dexpi.org/

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