SAREF4INMA: a SAREF extension for the Industry and Manufacturing domain

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Abstract. The IoT landscape is characterized by a fragmentation of standards, platforms and technologies, often scattered among different vertical domains. To prevent the market to continue to be fragmented and power-less, a protocol-independent semantic layer can serve as enabler of interoperability among the various smart devices from different manufacturers that co-exist in a specific industry domain, but also across different domains. To that end, the SAREF ontology was created in 2015 with the intention to interconnect data, enabling the communication between IoT devices that use different protocols and standards. A number of industrial sectors consequently expressed their interest to extend SAREF into their domains in order to fill the gaps of the semantics not yet covered by their communication protocols. Therefore, the SAREF4INMA ontology was recently created to extend SAREF for describing the Smart Industry & Manufacturing domain. SAREF4INMA is based on several standards and IoT initiatives, as well as on real use cases, and includes classes, properties and instances specifically created to cover the industry and manufacturing domain. This work describes the approach followed to develop this ontology, specifies its requirements and also includes a practical example of how to use it.

Keywords: industry 4.0, ontology, standard, SAREF, SAREF4INMA

1. Introduction

This paper presents the work carried out in a specialists task force (STF) requested by the European Telecommunication Standards Institute (ETSI) and the European Commission (EC) to extend the Smart Applications REFerence ontology (SAREF) to the Industry & Manufacturing domain[1]. This paper builds on the success achieved in the past years with SAREF [2], which is a reference ontology for IoT created in close interaction with the industry [1] during a study requested by the European Commission in 2015[3]. SAREF is published as an ETSI Technical Specification series that also includes dedicated extensions to specific domains (TS 103 410, parts 1-6). A proof-of-concept solution based on SAREF in the energy domain and implemented on existing commercial products[4] was demonstrated in 2017 [2].

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[1]https://portal.etsi.org/STF/stfs/STFHomePages/STF534
[2]https://ec.europa.eu/digital-single-market/en/blog/new-standard-smart-appliances-smart-home
[3]https://sites.google.com/site/smartappliancesproject
[4]https://ec.europa.eu/digital-single-market/en/news/digitalising-energy-sector-common-language-consumer-centric-world

The motivation behind SAREF is that the IoT landscape is characterized by a fragmentation of standards, platforms and technologies, often scattered among different vertical domains [3, 4] . To prevent the market to continue to be fragmented and power-less, a protocol-independent semantic layer can serve as enabler of interoperability [5] among the various smart devices from different manufacturers that co-exist in a specific industry domain (e.g., from lamps and consumer electronics to white goods, such as washing machines and ovens, which co-exist in our homes), but also across different domains. To that end, SAREF was created with the intention to interconnect data from different protocols and platforms, for instance ZigBee[5], UPnP (now OCF[6]) and Z-Wave[7], enabling the communication between in-home devices that use different protocols and standards. SAREF is not about the actual communication with devices and has not been set up to replace existing communication protocols, but it lays the base for enabling the translation of information coming from existing (and future) protocols to and from all other protocols that are referenced to SAREF. As confirmed in the EC's 'Rolling Plan for Information Communication and Technology standardization 2017', SAREF is the first ontology standard in the Internet of Things (IoT) ecosystem, and sets a template and a base for the development of similar standards for the other verticals to unlock the full potential of IoT.

Following the momentum gained during the smart appliances study, SAREF was published by ETSI as a Technical Specification [6]. In 2016, ETSI requested a first specialist task force (STF 513) to provide input on the management of SAREF and create dedicated extensions for specific domains[8]. The STF 513 was consequently established and developed extensions of SAREF in the energy [7], environment and building [8] domains . The STF 513 additionally developed an updated, more modular and flexible SAREF specification [9] using the feedback received from the industrial stakeholders since the first release of SAREF in 2015.

A number of industrial sectors consequently expressed their interest to extend SAREF into their domains in order to fill the gaps of the semantics not yet covered by their communication protocols nor by the existing SAREF extensions. To that end, a new STF 534 was launched in 2018 by ETSI with the goal to create SAREF extensions to the domains of Smart Cities, Smart Industry & Manufacturing, and Smart AgriFood, turning SAREF into the umbrella that enables better integration of semantic data from and across various vertical domains in the IoT. The STF 534 was concluded in April 2019 and consisted of two main tasks: 1) gather requirements, collect use cases and identify existing sources (e.g., standards, data models, ontologies, etc.) from the domains of interest (i.e., Smart Cities, Smart Industry & Manufacturing, and Smart AgriFood); and 2) produce extensions of SAREF for each domain based on these requirements. This paper focuses on the extension of SAREF to the Smart Industry & Manufacturing domain, which resulted in a new ontology, named SAREF for Industry and Manufacturing (SAREF4INMA), which is published as part of the SAREF series in a new ETSI Technical Specification [10]. The paper describes the approach used for developing SAREF4IMNA and, furthermore, presents the requirements, ontology design and a practical example of how to use and instantiate the SAREF4INMA extension.

The rest of the paper is structured as follows. Chapter 2 contains an overview of related work. Chapter 3 describes the methodology used while creating SAREF4IMNA. Next, Chapter 4 describes the requirements of the ontology and the ontology design itself. Chapter 5 elaborates on the application of the designed ontology to an example. Chapter 6 discusses the choices made during the ontology development, the impact of SAREF4IMNA, and its current limitations. Finally, Chapter 7 closes with the overall conclusions and future work.

2. Related work

In this section, the state of the art on ontologies and standards related to the industry and manufacturing domain is presented, including a brief description and their main features.

Among the relevant ontologies existing in the industry and manufacturing domain, ADACOR [11] is a manufacturing ontology which includes a taxonomy of manufacturing components and integrates concepts related to

[5] https://www.zigbee.org/
[6] https://openconnectivity.org/
[7] https://z-wavealliance.org/
[8] https://ec.europa.eu/digital-single-market/en/news/new-version-machine-2-machine-standard-smart-appliances-introduced-etsi

production orders and operations. Another ontology describing the manufacturing domain is MASON [12] upper ontology, which is built upon three head concepts: (1) entities, which aims to provide concepts to specify the product; (2) operations, which are related to process descriptions; and (3) resources, which stand for the whole set of manufacturing linked resource. Finally, OntoCAPE [13] is a large-scale ontology for chemical process engineering which has been used in three applications, namely, automatic selection of software components, computer-aided construction of mathematical models, and semantic annotation of document. It is divided into different modules, including material, chemical process system and simulation.

Regarding industrial initiatives, there are various member states initiatives aimed to support the digitisation of European industry and manufacturing, such as platform "Industry 4.0"[9] in Germany, "Industria 4.0"[10] in Italy, "Industrie du futur"[11] in France and the "Smart Industry initiative"[12] in the Netherlands. These initiatives focus on several aspects such as: 1) cyberphysical systems; 2) digital manufacturing technologies; and 3) new business models and propositions.

These initiatives collect different standards related to industry and industry 4.0. Such standards include IEC 62794 [14], which is a reference model for automation assets and structural and operational relationships; IEC 62832 [15], which identifies the general principles of the Digital Factory framework (i.e., a set of model elements and rules for modelling production systems); IEC 62264 [16], which describes the manufacturing operations management domain and its activities; IEC 61512 Batch control [17], which is a reference model for batch control as used in the process industries; IEC 62541 OPC UA [18], which describes the OPC UA Architecture, machine to machine communication protocol for industrial Author Guidelines 5 automation; IEC 62890 [19], which describes the lifecycle management for systems and products used in industrial process measurement, control and automation; IEC 61360 ISO 13584 [20], which specifies a general purpose dictionary covering the field of electro technology, electronics and related domains; IEC 62424 Topology [21], which specifies procedures and specifications for the exchange of Process Control Engineering relevant data provided by the Piping and Instrumentation Diagram (P&ID) tool; and IEC 62714 AutomationML [22], which defines a data exchange solution based on an XML schema for the domain of automation engineering and integrates IEC 61131 [23], IEC 62424 and ISO/PAS 17506 [24].

After analyzing the existing ontologies in the state of the art, we concluded that none of them covers the industry standards mentioned above, which were of key importance for the creation of SAREF4INMA. Furthermore, these state of the art ontologies do not focus on inter-organizational material and item measurement tracing, which are especially relevant for interoperability purposes. Therefore, whilst we could not reuse directly these ontologies, the collected standards from the various Industry 4.0 initiatives were used as the main input to provide use cases and requirements to SAREF4INMA, as described in our earlier paper [25].

3. Methodological background

The ontology presented in this work was built following the LOT (Linked Open Terms) methodology, which was first introduced in [26] and further developed in [27]. Additionally, this methodology was also proposed by ETSI in the Technical Report 103 411: SmartM2M Smart Appliances SAREF extension investigation [28] in order to develop the SAREF ontologies. The LOT methodology, which is built on top of the ontological engineering activities defined in the NeOn methodology [29], is based on agile techniques where the development of the ontology is organized in sprints or iterations.

This methodology defines iterations over the following activities: 1) Ontological requirements specification; 2) Ontology implementation; 3) Ontology publication; and 4) Ontology maintenance. Figure 1 summarizes these activities, together with their inputs, outputs and actors involved in them. More details related to LOT are available online in its website.[13]

[9] https://www.plattform-i40.de
[10] https://www.mise.gov.it/index.php/en/202-news-english/2036690-national-industry-4-0-plan
[11] http://www.industrie-dufutur.org/
[12] https://www.smartindustry.nl/english/
[13] http://lot.linkeddata.es/

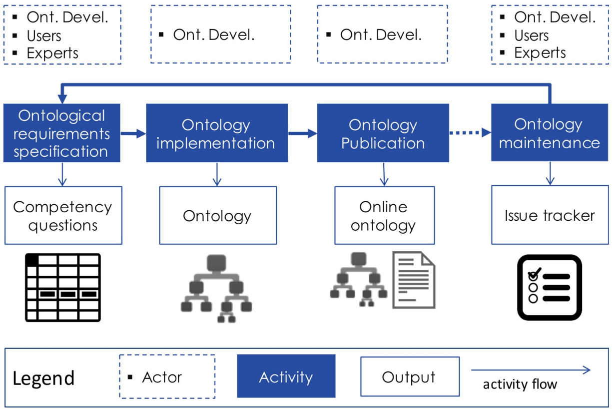


Fig. 1. LOT workflow with inputs, outputs and actors

For each of the above-mentioned activities, the following sections present the main definitions and guidelines provided by the methodology.

3.1. *Ontology requirements specification*

The goal of the ontological requirements specification process is to extract the set of requirements that will guide the implementation and validation of the ontology. These ontological requirements aims to state why the ontology is being built, what its intended uses are, who the end-users are, and which requirements the ontology should fulfill. There are two types of requirements: functional requirements, which refer to the particular knowledge to be represented by the ontology, and non-functional requirements, which refer to the characteristics, qualities, or general aspects not related to the ontology content that the ontology should satisfy.

The LOT methodology proposes the exchange of different documents, such as manuals, API specifications, datasets, standards or formats used in the community, between domain experts, ontology users and the ontology development team. From all the documentation, the ontology development team proposes a set of ontological requirements which can be written as Competency Questions [30] or in the form of natural language sentences. Such list of ontological requirements should be validated and completed together with domain experts.

3.2. *Ontology implementation*

During the ontology implementation activity, the ontology is built using a formal implementation language based on the ontological requirements identified in the previous activity.

The ontology implementation is usually divided into the following sub-activities:

- **Conceptualization**: It refers to the activity of organizing and structuring the information obtained during the acquisition process into meaningful models at the knowledge level according to the ontology specification document [29]. This conceptualization is usually carried out by means of diagrams or description logics statements.
- **Encoding**: It refers to the activity of generating computable models according to the syntax of a formal representation language, such as OWL [29]. To create such ontology encoding tools such as Protégé [14] or TopBraid [15] can be used.
- **Evaluation**: It refers to the activity of checking the technical quality of an ontology against a frame of reference [29]. Such evaluation can be related to different evaluation criteria, e.g., logical consistency checking, modelling issues or completeness. Some example of tools that can be used to validate ontologies are OOPS!

[14]https://protege.stanford.edu
[15]http://www.topquadrant.com/products/TB_Composer.html

(OntOlogy Pitfall Scanner![16]) [31] for bad design practices detection, Themis [17] for checking that the ontology fulfill all the proposed requirements, and the Hermit[18] or Pellet[19] reasoners to check that the ontology is consistent.
– **Reuse**: During this activity the ontology reuse activity can also be carried out. In this ontology reuse activity, the ontology development team should search for existing ontologies in order to reuse them. Experienced developers may carry out the ontology reuse also during the conceptualisation activity as they may be are aware which ontologies or set of ontologies to reuse before the encoding.

3.3. Ontology publication

The aim of this activity is to make the ontology available online both as a human-readable documentation and in a machine-readable format. The machine-readable format has to be obtained during the previous implementation activity, while the human-readable documentation should be carried out during this activity by describing, in HTML pages, the content of the ontology with diagrams and examples to improve ontology readability and reusability.

It is worth noting that these two versions of the ontology, both the code and the documentation in HTML, should be reached from the same URI using content negotiation mechanisms. There are tools that ease this publication activity, such as Widoco [32] or LODE,[20] which generate HTML documentation from the ontology encoding.

3.4. Ontology maintenance

During this activity the ontology is updated with new information, which may be needed after new requirements identification or bugs detection. This activity can be triggered during or after the ontology development process, if new requirements or bugs are detected, or if a new version of the ontology needs to be generated.

4. SAREF4INMA ontology development

Along this section it is described how each of the activities presented in Section 3 was carried out during the development of the SAREF4INMA ontology.

4.1. SAREF4INMA ontological requirements

The ontology requirement specification activity was carried out using two different inputs: (1) Standards and (2) Use Cases. First, an analysis of the standards in Industry and Industry 4.0 was carried out, identifying the more relevant terms and relations between them, as well as extracting definitions needed to model this domain. From all the analysed standards, which were presented in Section 2, only IEC 62890, which describes the lifecycle management for systems and products, IEC 62264, which describes the manufacturing operations management, and IEC 61512, which describes the batch control in the industry processes, were considered as relevant for the SAREF4INMA ontology domain.

Second, we extracted several concepts from the *Zero defect manufacturing* use case. Zero defect manufacturing focuses on reducing the yield loss of production to zero, often combined with an increase in flexibility. To that end, a combination of precision manufacturing technology, data collection and process control is needed. Two cycles are especially needed in the zero defect manufacturing use case, i.e., a real-time loop, that focuses on the immediate collection of data from sensors in or around a production equipment, and a data collection and analysis loop, that focuses on achieving a continuous process analysis and improvement. This use case is further detailed in the Technical Specification document of the SAREF extension for Industry and Manufacturing [33].

[16]http://oops.linkeddata.es/
[17]http://themis.linkeddata.es/
[18]http://www.hermit-reasoner.com/
[19]https://www.w3.org/2001/sw/wiki/Pellet
[20]https://github.com/essepuntato/LODE

From these two inputs, a first proposal of ontological requirements written both as competency questions and natural language sentences was generated. Such requirements were divided into four categories: (1) Requirements for Machine/Production Equipment, (2) Requirements for Material, (3) Requirements for Product and (4) Requirements for Factory. Each ontological requirement included:

– **Identifier**, unique for each requirements.
– **Competency question or natural language sentences**, which define the requirement the ontology should fulfill.
– **Possible answer**. In case the requirement is written as a competency question it should include an answer from which ontology needs are also leverage.
– **Category**, which indicates the domain of each requirement.
– **Provenance**, which represents the source from which they each requirement is extracted.

Once the first ontological requirements proposal was written, the domain experts validated it in order to determine if some of the requirements were incorrect and to add new ones. Table 1 shows an excerpt of the gathered requirements along with the source from which they were extracted, i.e., standard or use case. The complete list of ontological requirements for SAREF4INMA is presented in [33].

Id	Competency Question/Statement	Possible answer	Category	Provenance
INMA-1	What sort of production equipment is used in the factory?	Milling machine, stamping machine, moulding machine.	Machine/Production Equipment	Zero defect manufacturing use case
INMA-33	What kind of incoming material is used in the machine?	An individual item, a sub-assembly composed of different items or a volume of raw material	Material	Zero defect manufacturing use case
INMA-41	Products can be distinguished in categories		Product	IEC 62890
INMA-52	A site is located in a factory		Factory	IEC 62264

Table 1

Excerpt of requirements for SAREF4INMA

4.2. *SAREF4INMA implementation*

Taking as input the requirements defined in the previous activity, a conceptualization of the ontology was proposed. This conceptualization includes the most relevant concepts to model the industry domain, such as production equipment, item, batch and measurement. Figure 2 shows an overview of such conceptualization, where arrows with white triangles on top represent the *rdfs:subClassOf* relation between two classes. The origin of the arrow is the class to be declared as subclass of the class at the destination of the arrow. In addition, directed arrows are used to represent properties between classes. The ontologies in which each concept or relation is defined is indicated by the use of prefixes, for example the concept *s4inma:Item* is defined in the *https://w3id.org/def/s4inma#* namespace. As it is shown in this figure, SAREF4INMA also reuses terms from the SAREF ontology,[21] such as *saref:FeatureOfInterest*, and the SAREF4BLDG ontology,[22] such as *s4bldg:Building*. This format also applies to the other figures in the rest of the paper.

Figure 3 shows in detail the terms defined in SAREF4INMA related to items and batches. A *s4inma:Item* is a tangible object that represents either the goods produced by an organization's production process or individually traced supplies. Additionally, such *s4inma:Item* can be individually traced using a *s4inma:ID*, which can be defined in the form of GTIN,[23] International Registration Data Identifier (IRDI)[24] or Universally Unique Identifier (UUID),[25] and can consist of other *s4inma:Item*. Each *s4inma:Item* is created in a *s4inma:ItemBatch*, which describes a uniform collection of items produced at a certain time using a certain *s4inma:ProductionEquipment*.

[21]https://w3id.org/saref#
[22]https://w3id.org/def/saref4bldg#
[23]https://www.gs1.org/standards/id-keys/gtin
[24]https://stats.oecd.org/glossary/detail.asp?ID=1404
[25]https://www.itu.int/en/ITU-T/asn1/Pages/UUID/uuids.aspx

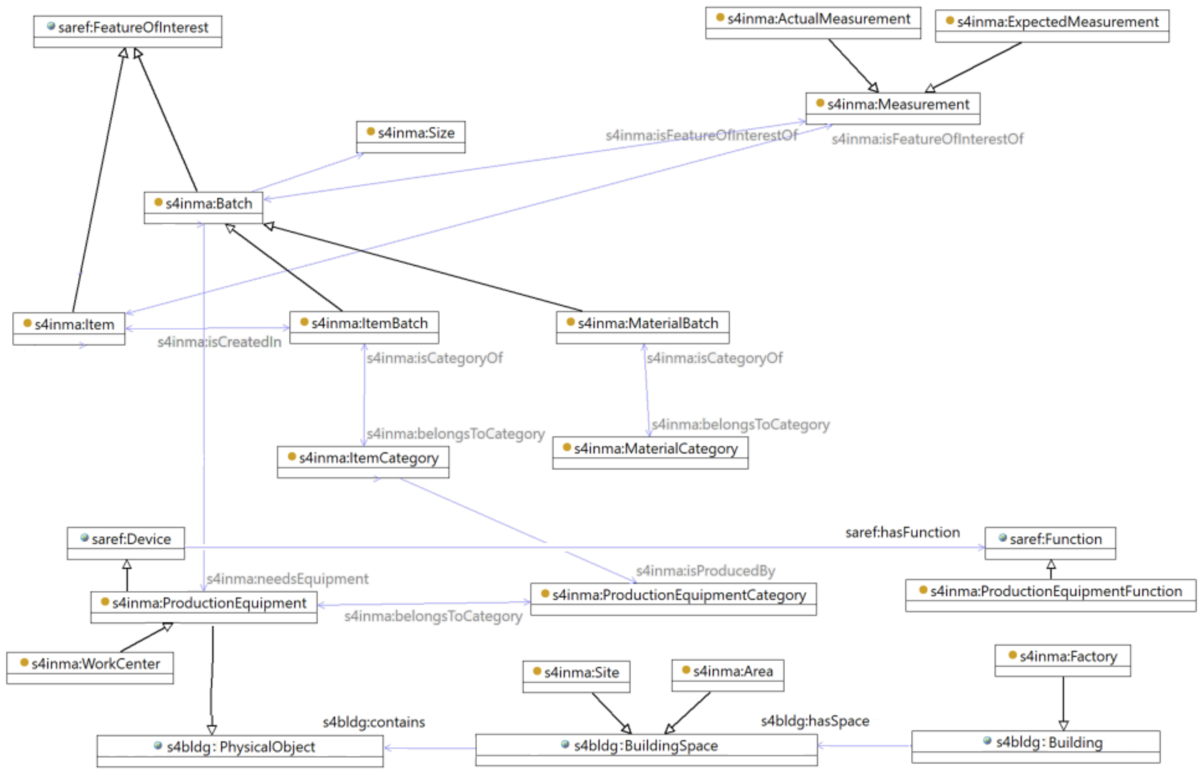


Fig. 2. SAREF4INMA conceptualization overview

SAREF4INMA also defines concepts related to production equipment and factory, in order to describe how a production equipment is organized and how it can exchange information within the factory. Figure 4 shows the terms related to production equipment and factory. A *s4inma:ProductionEquipmentCategory* describes the type of production equipment required for producing a certain *s4inma:Item*, i.e., describes the category of a machine. An organization might have multiple instances of the same category of machines. Each particular machine is represented by a *s4inma:ProductionEquipment*, which is a subclass of *saref:Device*, which is in turn a subclass of *s4bldg:PhysicalObject*.

Moreover, an *s4imna:Item* can recursively consist of other items (e.g., a shaver consists of a specific motor) and can consists of *s4imna:Batch* (e.g., a shaver consists of some raw plastic material). An item is created exactly in one *s4imna:ItemBatch*, which describes a uniform collection of items produced at a certain time using a certain production equipment. An *s4imna:ItemBatch* consists of a set of items with similar properties (e.g., a certain brand and model of sensors made using a certain production line). A *s4imna:ItemBatch* is a specialization of the more general *s4inma:Batch*, similarly to *s4inma:MaterialBatch*. The difference between *s4inma:ItemBatch* and *s4inma:MaterialBatch* is that individual items can be traced in an *s4inma:ItemBatch* (e.g., it is possible to trace an individual metal sheet in an ItemBatch), whereas it is not possible to exactly trace material in a *s4inma:MaterialBatch*, (e.g., it is not possible to trace the exact piece of raw plastic material from a *s4inma:MaterialBatch*, as the raw plastic is a volume, not identifiable in a specific sheet like in the case of metal sheets).

SAREF4INMA also describes a factory layout, which allows to locate each *s4inma:ProductionEquipment*. A factory (*s4inma:Factory*) in SAREF4INMA can be divided into smaller spaces, namely: *s4inma:Site* and *s4inma:Area*. Additionally, a *s4inma:Area* contains one or multiple *s4inma:WorkCenter*, which is a set of equipment elements located in an area that performs production, storage or material movement.

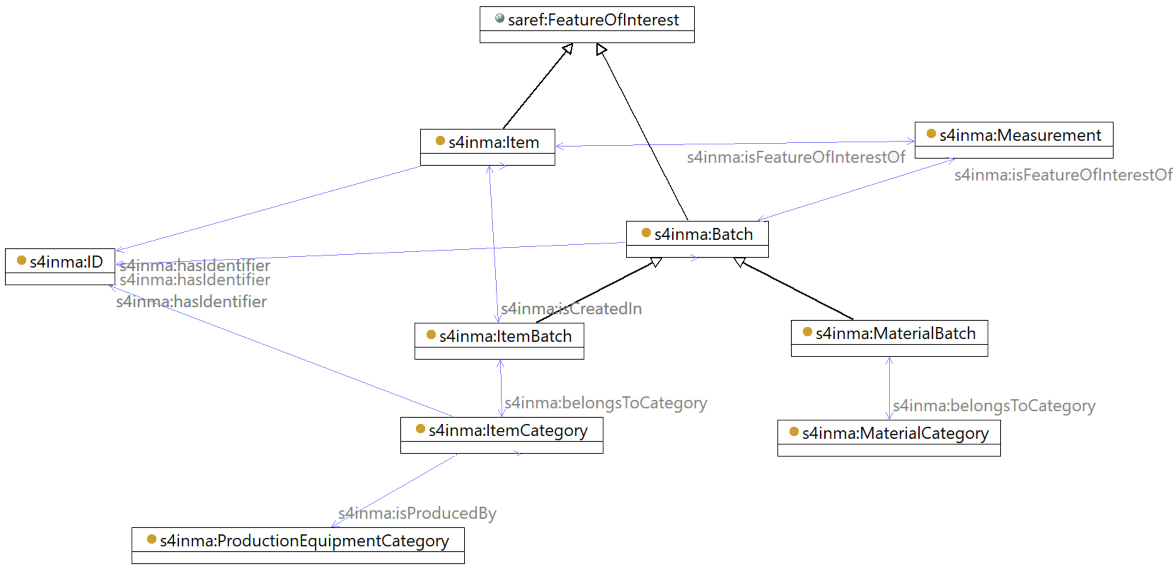


Fig. 3. SAREF4INMA Item, Batch and related classes

Finally, SAREF4INMA allows to trace back production process measurements to individual *s4inma:Item* or *s4inma:Batch*. The modelling of measurements in SAREF4INMA relies on the measurement model proposed in SAREF. According to the measurement model in SAREF, the *saref:FeatureOfInterest*[26] class represents the thing whose property is being measured. In addition, measurements (represented as *saref:Measurement*) are related to the property they observe (e.g., welding temperature) , its unit of measure (e.g., degrees Celsius) and the device carrying out such measurement.

In SAREF4INMA, the *s4inma:Measurement* class is created as a specialization of *saref:Measurement*. Such *s4inma:Measurement* further presents two specializations, namely *s4inma:ActualMeasurement* and *saref4inma:ExpectedMeasurement*, which are defined to describe the measurements that are planned or expected, and the measurements that are actually measured during the production process.

Additionally, the *s4inma:Measurement* can be related to a specific *s4inma:Batch* or *s4inma:Item*, which are both subclasses of *saref:FeatureOfInterest*. The *saref:FeatureOfInterest* class provides the means to refer to the real world phenomena that is being observed in the given measurement (e.g., a shaver is an item resulting from a certain production process and it can be defined as the feature of interest of a temperature measurement made by a welding machine used to join different parts in the production of the shaver). Figure 5 summarizes this measurement conceptualization.

Once the SAREF4INMA conceptualization was defined, it was encoded in OWL using Protégé[27] and stored in the GitHub repository[28]. Finally, we evaluated the ontology using OOPS!, as shown in Figure 6, and fixed the pitfalls related to the implementation of our ontology. As the figure below shows, no critical pitfalls have been detected.

[26]The saref:FeatureOfInterest class is not included in the current SAREF ontology v2.0 yet, but is planned to be added in the upcoming version v3.0

[27]https://protege.stanford.edu

[28]https://github.com/mariapoveda/saref-ext/tree/master/SAREF4INMA

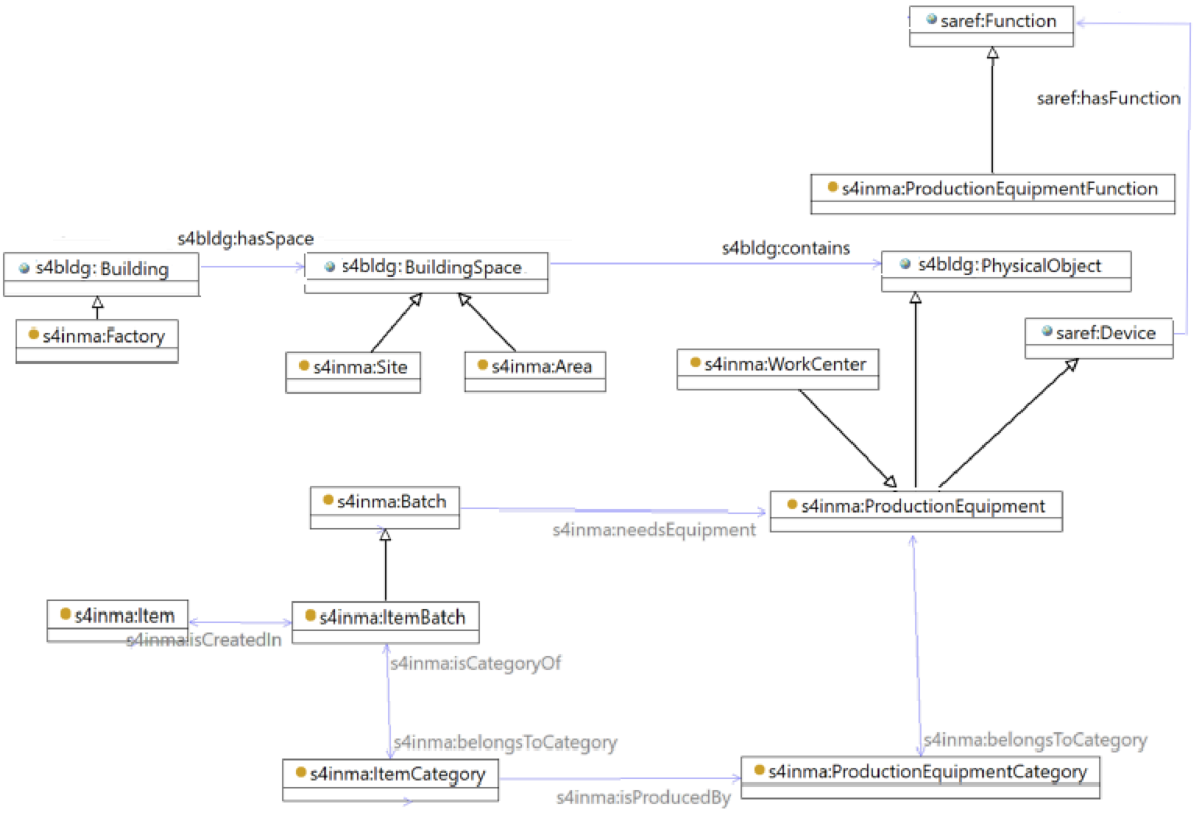


Fig. 4. SAREF4INMA Production Equipment, Factory and related classes

4.3. *SAREF4INMA publication and maintenance*

Once the ontology is encoded, it has to be published online. For this purpose it was used OnToology [34], a web-based system that builds on top of Git-based environments and integrates a set of existing tools for documentation, evaluation and publication activities. These integrated tools are Widoco [32] for generating the HTML documentation, AR2DTool[29] for generating diagrams, and OOPS![31] for evaluating the ontology. Additionally, OnToology provides two alternatives for ontology publication with content negotiation mechanisms, namely: (1) publishing the ontology with a permanent id using the *https://w3id.org* services or (2) downloading a bundle with all the archives needed to publish the ontology in a server. For the SAREF4INMA ontology the first option was selected, publishing the ontology under the URI *https://w3id.org/def/saref4inma#*. Therefore, the SAREF4INMA ontology is available in *https://w3id.org/def/saref4inma#* as machine-readable format and as a human-readable document by using content negotiation.

In order to support the maintenance activity in SAREF4INMA, the Github issue tracker[30] is used. Therefore, if users, domain experts, or ontology developers want to propose new requirements, detect bugs or have any suggestion, they have to create an issue in the Github repository. This issue tracker allows to keep track of all the issues

[29]https://github.com/idafensp/ar2dtool
[30]https://github.com/mariapoveda/saref-ext/issues

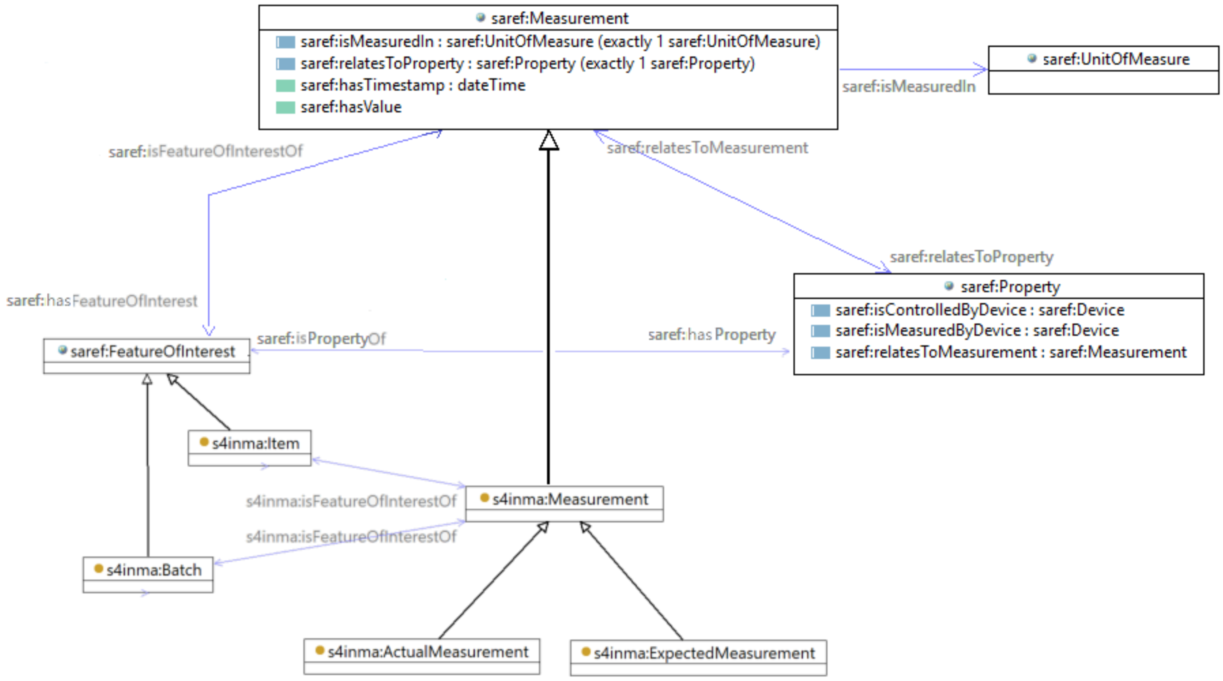
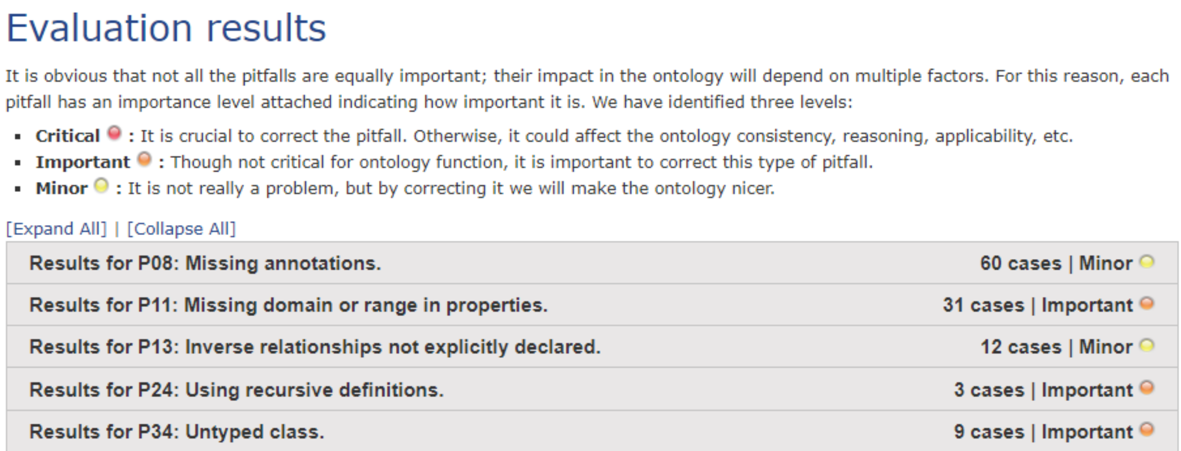


Fig. 5. SAREF4INMA Measurements and related classes



Evaluation results

It is obvious that not all the pitfalls are equally important; their impact in the ontology will depend on multiple factors. For this reason, each pitfall has an importance level attached indicating how important it is. We have identified three levels:

- **Critical** : It is crucial to correct the pitfall. Otherwise, it could affect the ontology consistency, reasoning, applicability, etc.
- **Important** : Though not critical for ontology function, it is important to correct this type of pitfall.
- **Minor** : It is not really a problem, but by correcting it we will make the ontology nicer.

[Expand All] | [Collapse All]

Results for P08: Missing annotations.	**60 cases | Minor**
Results for P11: Missing domain or range in properties.	**31 cases | Important**
Results for P13: Inverse relationships not explicitly declared.	**12 cases | Minor**
Results for P24: Using recursive definitions.	**3 cases | Important**
Results for P34: Untyped class.	**9 cases | Important**

Fig. 6. Results of the SAREF4INMA ontology evaluation perfomed by OOPS!

proposed by users, domain experts and developers ontology developers. Once an issue is open, it has to be discussed by the ontology development team in order to decide if the proposal presented in such issue should be implemented in the ontology or rejected.

It is worth mentioning that is planned to migrate SAREF4INMA and all the SAREF extensions to a repository under the European Telecommunications Standards Institute (ETSI) infrastructure. Therefore, once such repository is available all the issues will be managed from such infrastructure.

5. SAREF4INMA example

This section provides an example of how users can instantiate SAREF4INMA. This instantiation uses the *ex* prefix to indicate the instances created for such example, and the prefix *s4inma*, which indicates the SAREF4INMA ontology on which the *ex* example instantiation is built upon.

The example is shown in Figure 7 and represents an instance of a shaver, namely the *ex:Shaver10023*, of the *s4inma:Item* class. This shaver is an item created in a batch, and belongs to a category of items called PhilBrau S40 Premium Gold Shaver ItemCategory, represented by the *ex:PhilBraue_S40_Premium_Gold_Shaver_ItemCategory* instance of the *s4inma:ItemCategory* class.

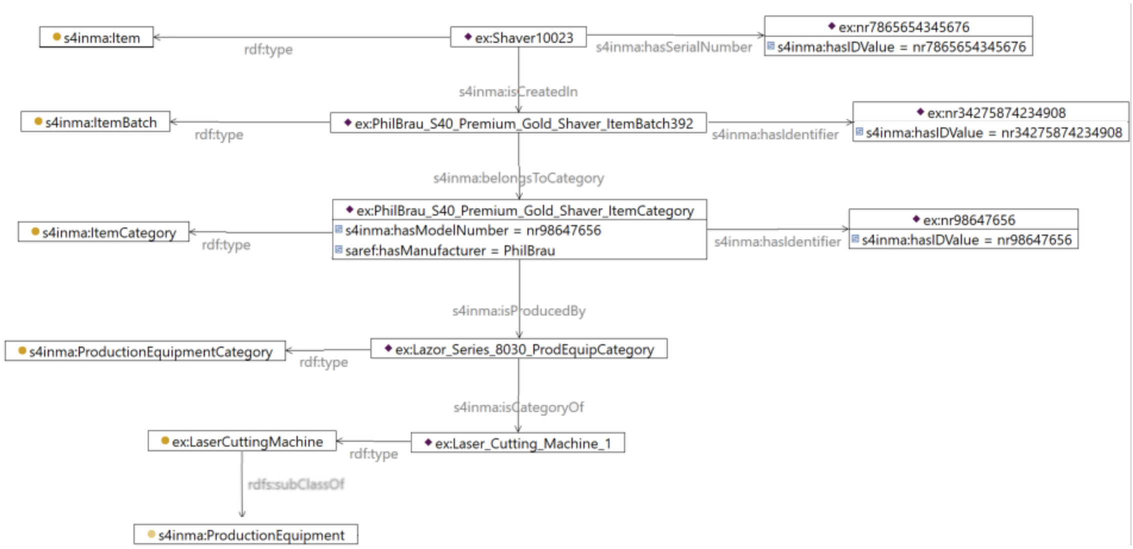


Fig. 7. SAREF4INMA Item example

As shown in Figure 8, the *ex:Shaver10023* item recursively consists of other three items, namely the *ex:ShaverHead3002*, *ex:StepMotor083* and *ex:ShaverBody9440* items. The *ex:ShaverBody9440* item is created in the *ex:PhilBrau_S40-S50_Generic_Body_ItemBatch3290*, which consists of material from other batches such as the Torx screws Batch 323 and ABS Plastic Batch 742, represented in the ontology example as *ex:Torx_screws_-D2mm_L8mm_MaterialBatch323* and *ex:ABS_Plastic_Role_8mm_MaterialBatch742*, respectively. These two material batches belong to two material categories classes created specifically for this example, respectively the *ex:Screw* class and the *ex:Plastic* class.

The production equipment example in Figure 9 defines two types of production equipment categories, namely the *ex:Lazor_Series_8030_ProdEquipCategory* and the *ex:WandI_Welding_Series_1000_ProdEquipCategory*. These categories represent models of production equipment and not the individual machines, since an organization might have multiple machines of the same model. For example, there is one laser cutting machine of type *ex:Lazor_Series_8030_ProdEquipCategory*, namely the *ex:Laser_Cutting_Machine_1*, and two individual welding machines, namely *ex:Welding_Machine_1* and *ex:Welding_Machine_2*.

Figure 9 shows the *ex:Welding_Machine_1* and the *ex:Welding_Machine_2*, which are instances of the *ex:WeldingMachine* and the *ex:LaserCuttingMachine* classes created for this example. Both these classes are subclasses of *s4inma:ProductionEquipment*, which is, in turn a subclass of *saref:Device*. The subclass relation of *s4inma:ProductionEquipment* and *saref:Device* ensures that a *s4inma:ProductionEquipment* can reuse SAREF functionalities, such as the possibility to perform functions with the object property *saref:hasFunction* or to control properties with the object property *saref:controlsProperty*. This is shown in the *ex:Welding_Machine_2* production equipment, which performs an *ex:JoiningFunction*, controls the *ex:WeldingTemperature* property, and consists of other devices such as the *ex:WeldingMachineTemperatureSensor1*.

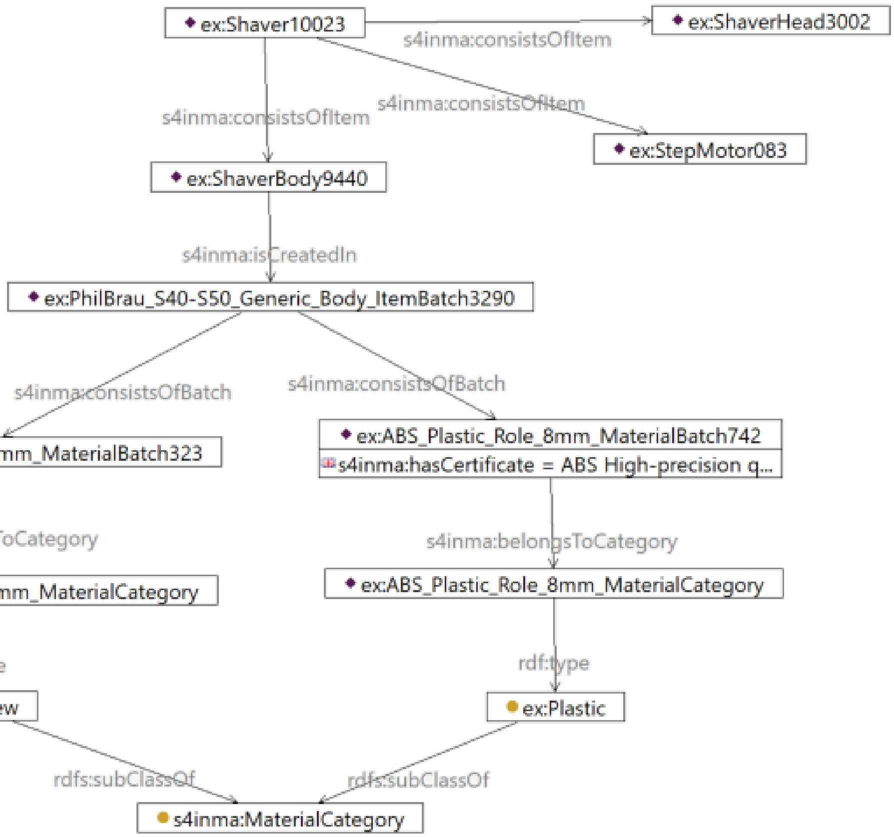


Fig. 8. SAREF4INMA Material example

6. Discussion

As mention in previous sections, for creating the SAREF4INMA ontology several standards were analysed. Such standards include information about equipment, factories, material, storage or measurements, among other topics. However, after a thorough analysis of the zero defect manufacturing use case [25] and interviews with domain experts, it was decided to leave some of these topics out of scope, such as those related to material and storage. Furthermore, it was decided not to model all categories of material and production equipment, but instead provide a structured method, which is similar to the mechanism in IEC 62890, to add new types of material and production equipment to the ontology in order to ensure that the user can easily relate their categories to the model.

Moreover, similarly to SAREF, it was decided not to model the organizational actors (e.g. organizations, employees, skills, ownership of machines), but instead fully focus on the industry and manufacturing domain. The organizational actors are not domain specific for SAREF4INMA and, therefore, they were left out in this first version of the ontology. There are other existing ontologies, such as FOAF[31] or The Organization Ontology[32], which model the organizational actors and can easily be integrated into future versions of SAREF4INMA.

Moreover, it was decided to re-use as much as possible the current available standards by, for example, creating mappings between current standards or use part of the functionality of a standard in the model. An example of this is that SAREF4INMA is mapped to the Smart Connected Supplier Network (SCSN) standard [35], which is a com-

[31] http://xmlns.com/foaf/spec/
[32] https://www.w3.org/TR/vocab-org/

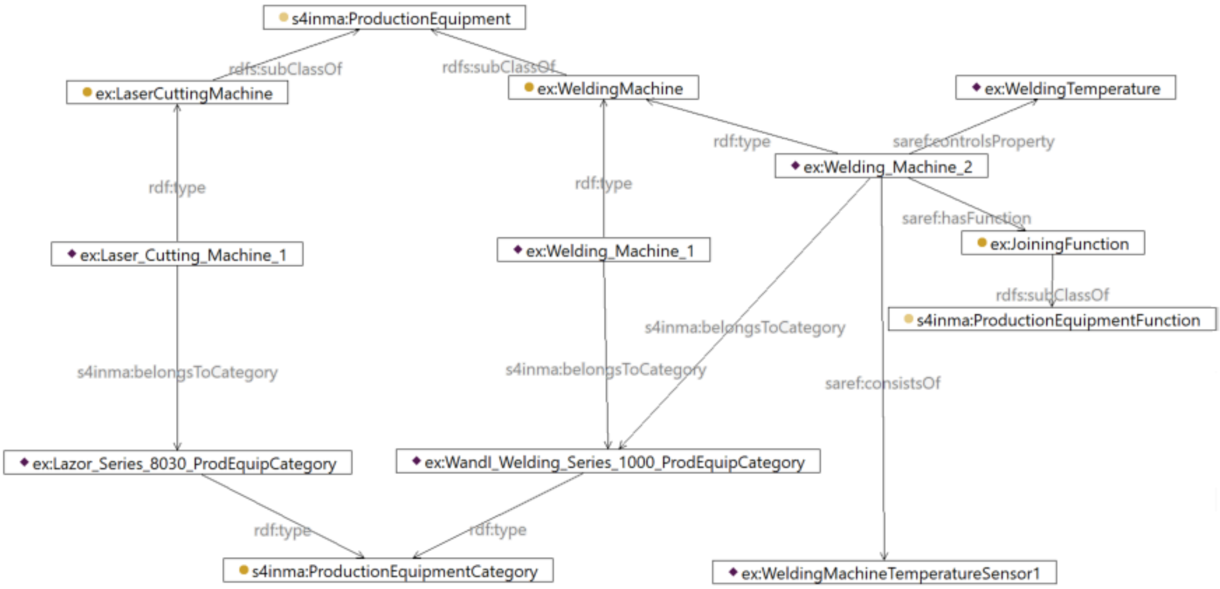


Fig. 9. SAREF4INMA Production equipment example

munication standard used by the high-tech equipment manufacturing sector for inter-organizational data exchange. This communication standard previously focused primarily on the procurement of goods. However, traceability of goods in the supply chain is an increasingly important topic in the industry, which requires new information being shared across the supply chain. SAREF4INMA can therefore serve as basis for further SCSN extensions, such as the possibility to exchange material certificates, of production process sensor information, and measurement reports between organizations.

7. Conclusions

In this work, the process followed to develop the SAREF extension for the industry and manufacturing domain, called SAREF4INMA, has been described. In addition, the ontology itself has been presented, together with an example of how such ontology can be instantiated.

SAREF4INMA represents a step forward with regard to the state of the art ontologies for the industry and manufacturing domain, as it describe production equipment in factories and allows to trace back and monitor production process measurements. Moreover, it describes a factory layout in order to be able to locate each production equipment in a factory. It is worth mentioning that this ontology was generated based on real-world use cases provided by domain experts and on several standards and industry 4.0 initiatives, such as Platform Industrie 4.0 from Germany. Based on these inputs, it was decided to keep out of scope the organizational actors, the material and the storage, while fully focusing on the industry and manufacturing domain.

Finally, an important aspect regarding the SAREF4INMA ontology is the fact that it was proposed in close collaboration with industry experts, who expect to adopt this extension in specific applications such as the Smart Connected Supplier Network communication standard.

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