ETSI TS 103 410-5 V1.1.2 (2020-05)

SmartM2M;
Extension to SAREF;
Part 5: Industry and Manufacturing Domains

Reference
RTS/SmartM2M-103410-5v112

Keywords
IoT, oneM2M, ontology, SAREF, semantic

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Sous-Préfecture de Grasse (06) N° 7803/88

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Foreword

This Technical Specification (TS) has been produced by ETSI Technical Committee Smart Machine-to-Machine communications (SmartM2M).

The present document is part 5 of a multi-part deliverable covering SmartM2M; Extension to SAREF, as identified below:

Part 1: "Energy Domain";

Part 2: "Environment Domain";

Part 3: "Building Domain";

Part 4: "Smart Cities Domain";

Part 5: "Industry and Manufacturing Domains";

Part 6: "Smart Agriculture and Food Chain Domain";

Part 7: "Automotive Domain";

Part 8: "eHealth/Ageing-well Domain";

Part 9: "Wearables Domain";

Part 10: "Water Domain".

Modal verbs terminology

In the present document "**shall**", "**shall not**", "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

"**must**" and "**must not**" are **NOT** allowed in ETSI deliverables except when used in direct citation.

1 Scope

The present document presents SAREF4INMA, a SAREF extension for the Industry and Manufacturing domains.

2 References

2.1 Normative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

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NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are necessary for the application of the present document.

[1] ETSI TS 103 264 (V3.1.1) (02-2020): "SmartM2M; Smart Applications; Reference Ontology and oneM2M Mapping".

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

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The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ETSI TR 103 411 (V1.1.1) (02-2017): "SmartM2M; Smart Appliances; SAREF extension investigation".

[i.2] ETSI TR 103 507 (V1.1.1) (10-2018): "SmartM2M; SAREF extension investigation; Requirements for industry and manufacturing domains".

[i.3] ETSI TS 103 410-3 (V1.1.2): "SmartM2M; Extension to SAREF; Part 3: Building Domain".

[i.4] ISO/IEC 11179-6: "Information technology -- Metadata registries (MDR) -- Part 6: Registration".

[i.5] ISO 29002 (all parts): "Industrial automation systems and integration -- Exchange of characteristic data".

[i.6] ISO 6532: "Portable chain-saws -- Technical data".

[i.7] BS EN 10204 (2004): "Metallic products -- Types of inspection documents".

[i.8] IEC 61512 (all parts): "Batch control".

[i.9] ISO/IEC 11578:1996: "Information technology -- Open Systems Interconnection -- Remote Procedure Call (RPC)".

[i.10] Recommendation ITU-T X.667/ISO/IEC 9834-8:2005: "Information technology -- Procedures for the operation of object identifier registration authorities: Generation of universally unique identifiers and their use in object identifiers".

[i.11] IEC 62264 (all parts): "Enterprise-control system integration".

3 Definition of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the following terms apply:

ontology: formal specification of a conceptualization, used to explicitly capture the semantics of a certain reality

3.2 Symbols

Void.

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

ABS	Acrylonitrile Butadiene Styrene
BIC	Brainport Industries Campus
BS	British Standard
EAN	European Article Number
EN	European Norm
GS1	Global Standards One
GTIN	Global Trade Item Number
GUID	Globally Unique IDentifier
ID	Identifier
IEC	International Electrotechnical Commission
IRDI	International Registration Data Identifier
ISO	International Organisation for Standardization
ITF	Interleaved 2 of 5
ITU-T	International Telecommunication Union - Telecommunications sector
OWL	Web Ontology Language
OWL-DL	Web Ontology Language - Description Logic
QR	Quick Response code
RAMI	Reference Architectural Model Industry 4.0
RFID	Radio Frequency Identification
RPC	Remote Procedure Call
SAREF	Smart Applications REFerence ontology
SAREF4BLDG	SAREF extension for buildings
SAREF4INMA	SAREF extension for industry and manufacturing domains
TR	Technical Report
TS	Technical Specification
UCC	Uniform Commercial Code
UPC	Universal Product Code
UPC-A	Universal Product Code

NOTE: UPC-A is an 11 digit variation of UPC, as opposed to UPC-E which is the 6 digit variation.

UUID	Universally Unique Identifier

4 SAREF4INMA ontology and semantics

4.1 Introduction and overview

The present document is a technical specification of SAREF4INMA, an extension of SAREF [1] that was created for the industry and manufacturing domain. SAREF4INMA was created to be aligned with related initiatives in the smart industry and manufacturing domain in terms of modelling and standardization, such as the Reference Architecture Model for Industry 4.0 (RAMI), which combines several standards used by the various national initiatives in Europe that support digitalization in manufacturing. These initiatives include, but are not limited to, the platform Industrie 4.0 in Germany, the Smart Industry initiative in the Netherlands, Industria 4.0 in Italy, the 'Industrie du future initiative' in France and more.

SAREF4INMA is an OWL-DL ontology that extends SAREF with 24 classes (in addition to a number of classes directly reused from the SAREF ontology and the SAREF4BLDG extension), 20 object properties (in addition to a number of object properties reused from the SAREF ontology and the SAREF4BLDG extension) and 11 data type properties. SAREF4INMA focuses on extending SAREF for the industry and manufacturing domain to solve the lack of interoperability between various types of production equipment that produce items in a factory and, once outside the factory, between different organizations in the value chain to uniquely track back the produced items to the corresponding production equipment, batches, material and precise time in which they were manufactured.

The full list of use cases, standards and requirements that guided the creation of SAREF4INMA are described in the associated ETSI TR 103 507 [i.2]. The "zero defect manufacturing" use case has been used as basis for the creation of SAREF4INMA in the present document. This use case is concerned with improving the manufacturing process in terms of flexibility to timely change from one manufactured product to another, generating as little yield loss as possible. Also the "smart services for product in use" and "smart product lifecycle" use cases are acknowledged in the associated ETSI TR 103 507 [i.2] as especially relevant for SAREF4INMA, as they pose semantic interoperability issues for, respectively:

1) the manufacturing companies that remain responsible for the proper functioning of a product during its entire lifecycle, also when the product has left the factory; and

2) the various, interacting parties involved in the value chain (e.g. manufacturer, user, servicing organization, parts supplier, etc.) that need to refer to a common digital footprint of a product to allow for its management during its entire lifecycle.

Note that SAREF4INMA specified in the present document provides a first SAREF extension for the industry and manufacturing domain, based on the (limited set of) use cases mentioned above and an initial list of standards for digitalization, communication, engineering and life-cycle, covering relevant concepts such as factory, production equipment, item, material and batch, as described in ETSI TR 103 507 [i.2]. However, as all the SAREF ontologies, SAREF4INMA is a dynamic semantic model that should be used, validated and improved over time with and by the stakeholders in the industry and manufacturing domain in an iterative and interactive manner to accommodate more use cases, standards and generate new requirements as needed.

The prefixes and namespaces used in SAREF4INMA and in the present document are listed in Table 1.

Table 1: Prefixes and namespaces used within the SAREF4INMA ontology

Prefix	Namespace
s4inma	https://saref.etsi.org/saref4inma/
saref	https://saref.etsi.org/core/
s4bldg	https://saref.etsi.org/saref4bldg/
dcterms	http://purl.org/dc/terms/
owl	http://www.w3.org/2002/07/owl#
rdf	http://www.w3.org/1999/02/22-rdf-syntax-ns#
rdfs	http://www.w3.org/2000/01/rdf-schema#
skos	http://www.w3.org/2004/02/skos/core#
om	http://www.wurvoc.org/vocabularies/om-1.8/
xsd	http://www.w3.org/2001/XMLSchema#
geo	http://www.w3.org/2003/01/geo/wgs84_pos#

4.2 SAREF4INMA

4.2.1 General Overview

An overview of the SAREF4INMA ontology is provided in Figure 1, where rectangles containing an orange circle are used to denote classes created in SAREF4INMA, while rectangles containing a green circle denote classes reused from other ontologies, such as SAREF or SAREF4BLDG. For all the entities described in the present document, it is indicated whether they are defined in the SAREF4INMA extension or elsewhere by the prefix included before their identifier, i.e. if the element is defined in SAREF4INMA the prefix is `s4inma`, while if the element is reused from another ontology it is indicated by a prefix according to Table 1 (e.g. `saref` refers to SAREF and `s4bldg` refers to SAREF for building).

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.

Directed arrows are used represent properties between classes.

Note that Figure 1 aims at showing a global overview of the main classes of SAREF4INMA and their mutual relations. More details on the different parts of Figure 1 are provided from clause 4.2.2 to clause 4.2.4.

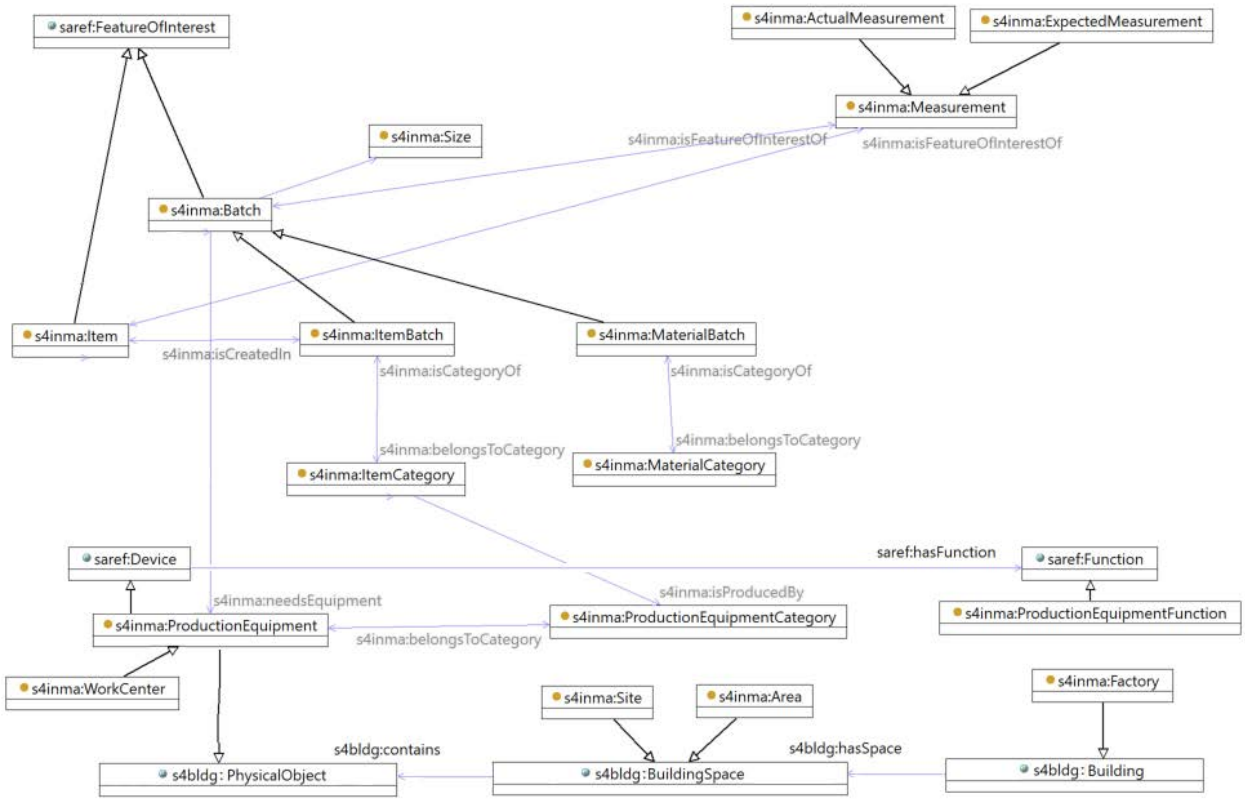

Figure 1: SAREF4INMA overview

Figure 2 shows the hierarchy of classes and properties defined in SAREF4INMA.

Orange circles represent classes of SAREF4INMA. Object properties - which are properties between two classes - are denoted by blue rectangles, while datatype properties - which are properties between a class and a data type, such as `xsd:string` or `xsd:dateTime` - are denoted by green rectangles.

Figure 2: SAREF4INMA classes and properties hierarchy

4.2.2 Item and Batch

This clause focuses on the classes of SAREF4INMA that describe an item produced in a factory. The classes of interest, which are `s4inma:Item`, `s4inma:ItemCategory`, `s4inma:MaterialCategory`, `s4inma:Batch`, `s4inma:ItemBatch`, `s4inma:MaterialBatch` and `s4inma:ID`, are shown in Figure 3.

An Item is a tangible object that represents either the goods produced by an organization's production process or individually traced supplies (i.e. sub-assemblies of supplies). An item can be individually traced using an ID. SAREF4INMA allows to use several types of IDs, such as the Global Trade Item Number (GTIN) defined by GS1 (https://www.gs1.org/), used by organizations to uniquely identify their trade items as products or services that are priced, ordered or invoiced at any point in the supply chain. There are four GTIN formats (GTIN-8, GTIN-12, GTIN-13, GTIN-14) and SAREF4INMA defines classes and properties for each of them. SAREF4INMA defines also classes and properties to associate items to the International Registration Data Identifier (IRDI), which is based on the international standards ISO/IEC 11179-6 [i.4], ISO 29002 [i.5] and ISO 6532 [i.6]. An example of relevant standard that uses IRDIs is the eCl@ss specification (https://www.eclass.eu/en/) for grouping materials, products and services. Other types of IDs are defined in SAREF4INMA, such as the Universally Unique Identifier (UUID), or can be further defined ad-hoc by the ontology users by creating new classes as subclasses of the `s4inma:ID` class.

An Item can recursively consist of other items (e.g. a shaver consists of a shaver head, motor and body) and can be the feature of interest of a measurement (e.g. a shaver can be the feature of interest of a temperature measurement made by a welding machine used to join different parts in the production of the shaver). An item is created exactly in one ItemBatch, which describes a uniform collection of items produced at a certain time using a certain production equipment. An 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). An ItemBatch is a specialization of the more general Batch, which can be further specialized in a MaterialBatch. The difference between ItemBatch and MaterialBatch is that individual items can be traced in an 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 MaterialBatch, (e.g. it is not possible to trace the exact piece of raw plastic material from a MaterialBatch, as the raw plastic is a volume, not identifiable in a specific sheet like in the case of metal sheets).

Material batches can be equipped with quality certificates, such as the BS EN 10204:2004 [i.7] category 3.1 steel quality certificate (https://standardsdevelopment.bsigroup.com). These certificates provide additional information about the material in the batch. Furthermore, MaterialBatches belong to some MaterialCategory, which describes a certain type of material (e.g. a certain type of steel sheets). Analogously, item batches belong to some ItemCategory, which describes a single type of Items (e.g. a certain type of sensor). An ItemCategory is in turn produced by some ProductionEquipmentCategory (see clause 4.2.3). The essential properties of each Item in all ItemBatches are the same. However, each ItemBatch might use different MaterialBatches and/or different ProductionEquipment. Therefore, small deviations between batches might occur, while the essential properties of all Items related to an ItemCategory are similar. Finally, the time that a batch is produced can be recorded using the `time:hasBeginning` and `time:hasEnd` properties.

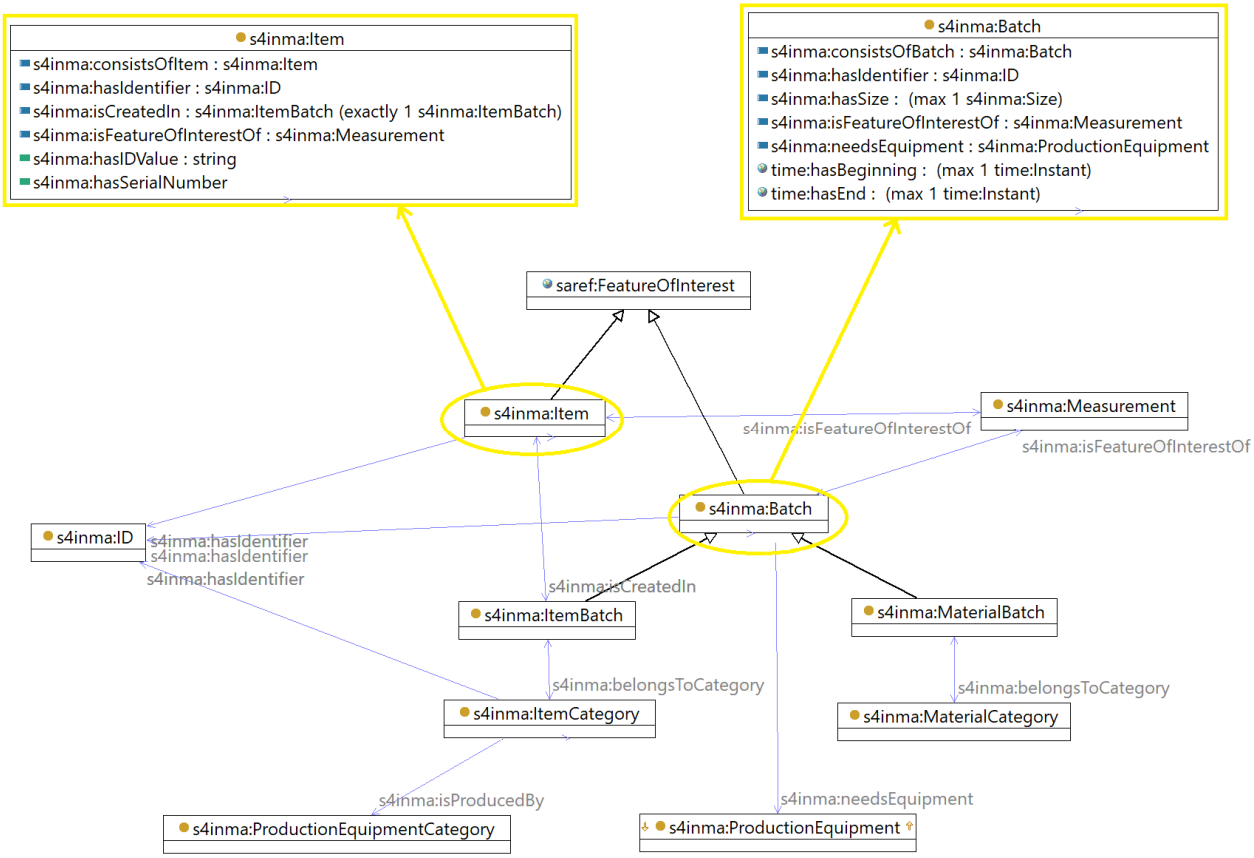

Figure 3: Item, Batch and related classes

Table 2 summarizes the definitions of the Item and related classes described above.

Table 2: Item, Batch and related classes: definitions

Class	Definition
s4inma:Item	A tangible object which can be unique identified, for example, with a GTIN in the form of a barcode/QR/RFID tag. An item can be the result of an organization's production process (i.e. outflow of objects/goods) or a uniquely identifiable material (i.e. inflow of objects/supplies). Each item is part of exactly one ItemBatch, whereas each ItemBatch contains only Items with similar properties. An item can consist of multiple Batches and other Items (i.e. subassemblies).
s4inma:Batch	A uniform collection of tangible objects or Lot. This can either be a collection of produced items (i.e. the outflow of products) or a collection of raw material or required material (i.e. the inflow of products). It is assumed that the objects in a batch are similar and thus have shared attributes. Note that this definition is broader than the definition in IEC 61512 [i.8], which defines a batch as the material that is being produced (whereas in SAREF4INMA a batch can be items or materials).
s4inma:ItemBatch	A uniform collection of tangible objects which are relevant for the production process. The ItemBatch consists of a set of objects with similar properties (e.g. a certain type of sensors or metal sheets). The difference between ItemBatch and MaterialBatch is that individual items can be traced in an ItemBatch, whereas this is not possible in a MaterialBatch, meaning that, for example, it is possible to trace the individual metal sheet used in an ItemBatch, but not the specific piece of plastic of a MaterialBatch (i.e. only the volume of plastic material from which a plastic item generated can be traced). This implies that the objects in an ItemBatch have a unique identifier (e.g. a GTIN code in the form of a barcode/QR-code or RFID tag).
s4inma:MaterialBatch	A uniform collection of tangible raw material which is relevant for the production process. The MaterialBatch can consist of a set of objects with similar properties (e.g. a certain type of screws) or a stock of homogeneous material (e.g. oil, water). The difference between MaterialBatch and ItemBatch is that individual items cannot be traced in a MaterialBatch, whereas this is possible in an ItemBatch, meaning that, for example, it is not possible to trace the individual screw used in a MaterialBatch.
s4inma:ItemCategory	An ItemCategory describes a category of item in terms of its static properties. Each ItemCategory can have multiple related ItemBatches, which all contain individual Items. The essential properties of each Item in all ItemBatches are the same. However, each batch might use different MaterialBatches and/or different ProductionEquipment. Therefore, small deviations between batches might occur, while the essential properties of all Items related to an ItemCategory are similar.
s4inma:MaterialCategory	A MaterialCategory describes a category of material in terms of its static properties. Examples are: a certain category of steel or plastic. Each MaterialCategory can have multiple related MaterialBatches, which represent the physical material. The essential properties of the material in all MaterialBatches are the same. However, each batch might use different MaterialBatches and/or different ProductionEquipment. Therefore, small deviations between batches might occur, while the essential properties of the material related to an MaterialCategory are similar.
s4inma:ID	A unique identifier.
s4inma:GTIN8ID	GTIN-8 (EAN/UCC-8) is an 8-digit number used predominately outside of North America.
s4inma:GTIN12ID	GTIN-12 (UPC-A) is a 12-digit number used primarily in North America.
s4inma:GTIN13ID	GTIN-13 (EAN/UCC-13) is a 13-digit number used predominately outside of North America.
s4inma:GTIN14ID	GTIN-14 (EAN/UCC-14 or ITF-14 or also known as ITF Symbol, SCC-14, DUN-14, UPC Case Code, UPC Shipping Container Code, UCC Code 128, EAN Code 128) is a 14-digit number used to identify trade items at various packaging levels.
s4inma:IRDI	International Registration Data Identifier (IRDI) is based on the international standards ISO/IEC 11179-6 [i.4], ISO 29002 [i.5] and ISO 6532 [i.6] and used in eCl@ss and the Asset Administration Shell as unique identifier.
s4inma:UUID	A universally unique identifier (UUID) is a 128-bit number used to identify items and is also known as: globally unique identifier (GUID). In its canonical textual representation, the sixteen octets of a UUID are represented as 32 hexadecimal (base 16) digits, displayed in five groups separated by hyphens, in the form 8-4-4-4-12 for a total of 36 characters (32 alphanumeric characters and four hyphens). UUID are documented in ISO/IEC 11578 [i.9]:1996: "Information technology -- Open Systems Interconnection -- Remote Procedure Call (RPC)" and in ITU-T Rec. X.667 | ISO/IEC 9834-8:2005 [i.10].
s4inma:Size	The amount of certain objects in a collection (e.g. size of a material batch).

Table 3 summarizes the properties that characterize an Item and the related classes described above.

Table 3: Properties of Item, Batch and related classes

Property	Definition
s4inma:Item s4inma:isCreatedIn **only** s4inma:ItemBatch	The relation between an Item and the ItemBatch in which it is created (inverse of s4inma:creates).
s4inma:Item s4inma:isCreatedIn **exactly** 1 s4inma:ItemBatch	An Item is created exactly in one ItemBatch.
s4inma:Item s4inma:consistsOfItem **only** s4inma:Item	An item can recursively consist of other Items.
s4inma:Item s4inma:hasSerialNumber **max** 1 xsd:string	An Item can have one serial number at most.
s4inma:Item s4inma:hasIdentifier **only** s4inma:ID	The relation between an item and its unique identifier.
s4inma:Item s4inma:hasIdentifier **some** s4inma:ID	An Item has a unique identifier (e.g. GTIN, IRDI, UUID, etc.).
s4inma:Item s4inma:hasIDValue **only** xsd:string	Alternative relation to the s4inma:hasIdentifier object property above, in case it is preferred to attach the ID as a string directly the Item.
s4inma:Item s4inma:isFeatureOfInterestOf **only** s4inma:Measurement	A relation between an item and the measurements it relates to, i.e. an item can be the feature of interest of a measurement (inverse of s4inma:hasFeatureOfInterest).
s4inma:ItemCategory s4inma:hasIdentifier **only** s4inma:ID	The relation between an item category and its unique identifier.
s4inma:ItemCategory s4inma:hasIdentifier **some** s4inma:ID	An item category has a unique identifier (e.g. GTIN, IRDI, UUID, etc.).
s4inma:ItemCategory s4inma:hasModelNumber **max** 1 xsd:string	An ItemCategory can have one model number at most.
s4inma:ItemCategory saref:hasManufacturer **max 1** xsd:string	A relation from SAREF identifying the manufacturer of an entity .
s4inma:ItemCategory s4inma:hasUpdate **only** s4inma:ItemCategory	An ItemCategory can have a new revision. The old version is related to the new version via the hasUpdate relation.
s4inma:ItemCategory s4inma:hasVersion **max** 1 xsd:string	An ItemCategory can have one version number at most. The combination of hasModelNumber and hasVersion should be unique.
s4inma:ItemCategory s4inma:isCategoryOf **only** s4inma:ItemBatch	A relation between a certain category of items and the associated item batches.
s4inma:ItemCategory s4inma:isProducedBy **some**s4inma:ProductionEquipmentCategory	An ItemCategory is produced using certain categories of machines (i.e. ProductionEquipmentCategory).
s4inma:Batch s4inma:consistsOfBatch **only** s4inma:Batch	A Batch can recursively consist of other batches.
s4inma:Batch s4inma:hasIdentifier **only** s4inma:ID	A Batch can have a unique identifier.
s4inma:Batch time:hasBeginning **max** 1 time:Instant	The production of the Batch started at a certain point in time (if recorded).
s4inma:Batch time:hasEnd **max** 1 time:Instant	The production of the Batch finished at a certain point in time (if recorded).
s4inma:Batch s4inma:hasSize **max** 1 Size	A relation to count the amount of certain objects in a collection (e.g. size of a batch).
s4inma:Batch s4inma:needsEquipment **only** s4inma:ProductionEquipment	A relation indicating that an entity needs a particular equipment to be produced.
s4inma:Batch s4inma:isFeatureOfInterestOf **only** s4inma:Measurement	A relation between a batch and the measurements it relates to, i.e. a batch can be the feature of interest of a measurement (inverse of s4inma:hasFeatureOfInterest).
s4inma:ItemBatch s4inma:belongsToCategory **only** s4inma:ItemCategory	An ItemBatch belongs to a certain category of Items. There can be multiple batches per category (i.e. type) of items.
s4inma:ItemBatch s4inma:creates **only** s4inma:Item	A relation of a production process (e.g. Batch) that creates one or more tangible objects (e.g. Items). Inverse of s4inma:isCreatedIn.
s4inma:MaterialBatch s4inma:belongsToCategory **exactly** 1 s4inma:MaterialCategory	A MaterialBatch belongs to a certain category of Material. There can be multiple batches per category.
s4inma:MaterialBatch s4inma:hasCertificate **only** xsd:string	The MaterialBatch can contain material quality certificates, for example a BS 10204:2004 [i.7] 3.1 steel certificate.

4.2.3 Production Equipment and Factory

This clause focuses on the classes that describe how a production equipment is organized and how it can exchange information within the factory. The classes of interest are: `s4inma:ProductionEquipment`, `s4inma:ProductionEquipmentCategory`, `s4inma:WorkCenter`, `s4inma:Area`, `s4inma:Site`, and `s4inma:Factory`, and are shown in Figure 4.

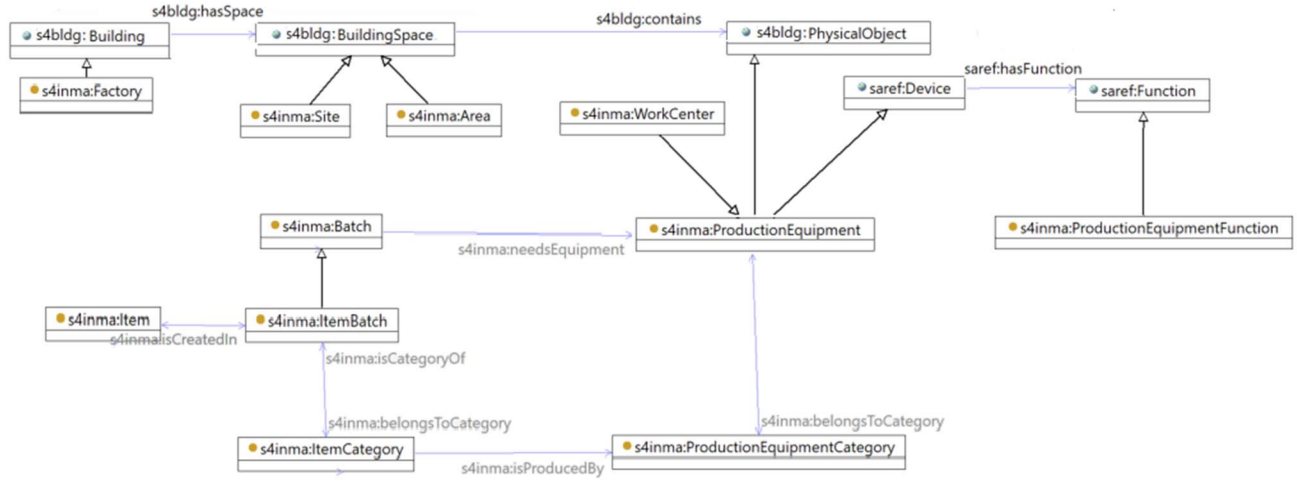

Figure 4: Production Equipment, Factory and related classes

A ProductionEquipmentCategory describes the kind of production equipment required for producing a certain item, i.e. a category of machine. An organization might have multiple instances of the same category of machines. Each individual machine is represented by a ProductionEquipment, which is a subclass of `saref:Device`, which is in turn a subclass of `s4bldg:PhysicalObject`. The latter is part of the SAREF for Building extension [i.3], which defines the `saref:Device` class as a subclass of the more general `s4bldg:PhysicalObject` class, following a pattern that allows to locate devices within the building. Analogously, SAREF4INMA reuses the same pattern to locate a production equipment in the factory.

In order to locate the ProductionEquipment, a factory layout can be created. A factory is represented by the `s4inma:Factory` class (which is subclass of the `s4bldg:Building` class) and can be further divided into smaller spaces using the `s4bldg:BuildingSpace` class. For the scope of SAREF4INMA, two types of BuildingSpaces are defined, namely Site and Area. A Factory can be further divided in sites, which according to IEC 62264 [i.11] are identified physical, geographical, and/or logical component groupings of a manufacturing enterprise. A Site can be divided in areas which are defined by IEC 62264 [i.11] as physical, geographical or logical groupings of resources determined by the site. An Area contains one or multiple work centers, which are a subclass of the `s4inma:ProductionEquipment` class and are defined according to IEC 62264 [i.11] as equipment elements under an area in a role-based equipment hierarchy that performs production, storage or material movement.

Note that as a subclass of `saref:Device`, a production equipment in SAREF4INMA inherits all the properties of devices defined in SAREF. This includes the possibility to associate a device (and therefore a production equipment) with a number of functions. For the purpose of SAREF4INMA, a new class of functions is created, namely the `s4inma:ProductionEquipmentFunction` class, which can be populated with subclasses that describe relevant functions, depending on the use case under consideration. For example, the instantiation of SAREF4INMA in clause 4.3 defines the CuttingFunction, FormingFunction and JoiningFunction subclasses, which describe functions that can be performed by different types of production equipment, such as LaserCuttingMachine, WeldingMachine, MillingMachine, MouldingMachine and StampingMachine.

Table 4 summarizes the properties that characterize the Production Equipment and Factory classes described above.

Table 4: Production Equipment, Factory and related classes: definitions

Class	Definition
s4inma:ProductionEquipment	A production equipment is a specialization of a saref:Device and s4bldg:PhysicalObject that can produce items in a manufacturing process. This class represents an individual production equipment machine and includes their specification in terms of functions, states and services. Different types of machines can be defined under this class as needed, for example, LaserCuttingMachine (i.e. a type of production equipment to cut steel material), MillingMachine (i.e. to drill holes in steel material), MouldingMachine (i.e. to mould liquid material, such as iron or plastic, and let it harden in a certain shape), WeldingMachine (i.e. to join together parts of material, such as steel), etc.
s4inma:ProductionEquipmentCategory	A ProductionEquipmentCategory represents a certain category of production equipment in terms of its static properties (e.g. a certain model and brand). Each ProductionEquipmentCategory can have multiple related ProductionEquipment, which represent the actual individual machines. Moreover, each ItemCategory can be produced by multiple ProductionEquipmentCategories.
s4inma:Factory	A subclass of s4bldg:Building specialized for the purpose of SAREF4INMA, a factory represents one or more organizations sharing a definite mission, goals and objectives which provides an output such as a product (definition taken from IEC 62264 [i.11]). A factory can be divided in one or multiple sites.
s4inma:Site	A subclass of s4bldg:BuildingSpace used to define the physical spaces of the building. According to IEC 62264 [i.111], sites are identified physical, geographical, and/or logical component groupings of a manufacturing enterprise. A factory can be divided in sites, whereas sites can be divided areas.
s4inma:Area	A subclass of s4bldg:BuildingSpace used to define the physical spaces of the building. According to IEC 62264 [i.11], areas are physical, geographical or logical groupings of resources determined by the site. A site can be divided in areas, whereas areas contain work centers.
s4inma:WorkCenter	A subclass of s4inma:ProductionEquipment (and therefore of s4bld:PhysicalObject). It is an equipment element under an area in a role-based equipment hierarchy that performs production, storage or material movement (definition taken from IEC 62264 [i.11]). An Area contains work centers.

Table 5 summarizes the properties that characterize a Production Equipment and the related classes described above.

Table 5: Properties of Production Equipment and Production Equipment Category

Property	Definition
s4inma:ProductionEquipmentCategory saref:hasName **only** xsd:string	A ProductionEquipmentCategory can be described using a name.
s4inma:ProductionEquipmentCategory saref:hasDescription **only** xsd:string	A ProductionEquipmentCategory can have an additional textual description.
s4inma:ProductionEquipmentCategory s4inma:hasModelNumber **only** xsd:string	A ProductionEquipmentCategory can be described using a model number.
s4inma:ProductionEquipmentCategory saref:hasManufacturer **only** xsd:string	A ProductionEquipmentCategory can be described using the manufacturer of the machine.
s4inma:ProductionEquipment s4inma:belongsToCategory **only** s4inma:ProductionEquipmentCategory	ProductionEquipment belongs to a certain category. There can be multiple individual ProductionEquipment per category.
s4inma:ProductionEquipment s4inma:hasIdentifier **only** s4inma:ID	The relation between a ProductionEquipment and its unique identifier.
s4inma:ProductionEquipment s4inma:hasIDValue **only** xsd:string	Alternative relation to the s4inma:hasIdentifier object property above, in case it is preferred to attach the ID as a string directly to the ProductionEquipment.
s4inma:ProductionEquipment saref:has manufacturer **max 1** xsd:string	A relation inherited from SAREF used in SAREF4INMA to identify the manufacturer of a production equipment.
s4inma:ProductionEquipment saref:has model **max 1** xsd:string	A relation inherited from SAREF used in SAREF4INMA to identify the model of a production equipment.
s4inma:ProductionEquipment saref:has description **max 1** xsd:string	A relation inherited from SAREF used in SAREF4INMA to provide the model of a production equipment.
s4inma:ProductionEquipment saref:consists of **only** saref:Device	A relation inherited from SAREF used in SAREF4INMA to indicate a composite production equipment that can recursively consist of other devices (e.g. sensors and actuators).
s4inma:ProductionEquipment saref:has function **min 1** s4inma: ProductionEquipmentFunction	A relation inherited from SAREF used in SAREF4INMA to identify the type of function of a production equipment.
s4inma:ProductionEquipment saref:has state **only** saref:State	A relation inherited from SAREF used in SAREF4INMA to identify the type of state of a production equipment.
s4inma:ProductionEquipment saref:measuresProperty **only** saref:Property	A relation inherited from SAREF used in SAREF4INMA to specify the Property that can be measured by a certain production equipment (or other devices composing it, such as sensors and actuators).
s4inma:ProductionEquipment saref:makesMeasurement **only** s4inma:Measurement	A relation inherited from SAREF used in SAREF4INMA between a production equipment or other devices composing it (e.g. sensors and actuators) and the measurements they make.

4.2.4 Measurement

An important aspect of SAREF4INMA is the ability to trace back production process measurements to individual items or batches. The modelling of measurements in SAREF4INMA totally relies on the measurement model proposed in SAREF. This modelling include the `saref:FeatureOfInterest` class that 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). The reader shall refer to the SAREF specification for details about the modelling of measurements. The following properties are reused in SAREF4INMA to complete the model of measurements:

- `saref:isPropertyOf` (and its inverse `saref:hasProperty`) to link the property being observed with the feature of interest.
- `saref:hasFeatureOfInterest` (and its inverse `saref:isFeatureOfInterestOf`) to link a given measurement with the feature of interest being observed.
- `saref:measurementMadeBy` has been included as complement of the `saref:makesMeasurement`, as its inverse, to link a measurement and the device that produces it.

Note that the present document includes details only for the new concepts created in SAREF4INMA, such as the `s4inma:Measurement` class. The classes of interest for measurements are shown in Figure 5.

The `s4inma:Measurement` class is defined as a subclass of the more general `saref:Measurement` class. The `s4inma:Measurement` class is further specialized in the `s4inma:ActualMeasurement` and `s4inma:ExpectedMeasurement` classes to describe whether a certain measurement is planned (i.e. expected) or is actually measured during the production process (i.e. actual measurement). This enables the calculation of deviations between planned and actual production process measurements.

As a `saref:Device` can recursively consists of devices, a ProductionEquipment in SAREF4INMA can also consist of other devices, such sensors and actuators. A device (e.g. production equipment and its sensors) can make measurements. These measurements can be related to a specific `s4inma:Batch` or `s4inma:Item` (which are both subclasses of the `saref:FeatureOfInterest` class) via the`hasFeatureOfInterest` relation. Moreover, according to the measurement model in SAREF, measurements are related to the property they observe (e.g. welding temperature) and its unit of measure (e.g. degrees Celsius).

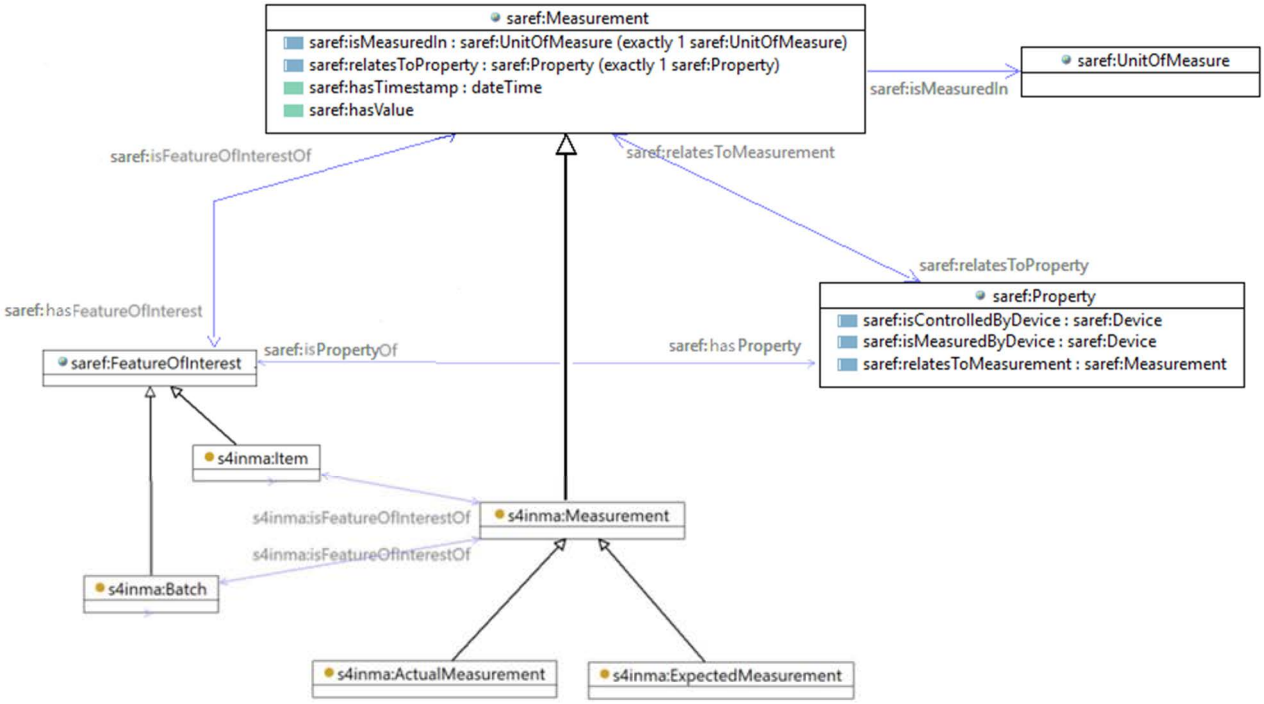

Figure 5: Measurement

Table 6 summarizes the properties that characterize the s4inma:Measurement class described above.

Table 6: Classes and Properties of Measurement

Property	Definition
s4inma:Measurement	A subclass of saref:Measurement that represents the measured value made over a property. It is also linked to the unit of measure in which the value is expressed and the timestamp of the measurement. The saref4imna:Measurement can be linked to individual Batches or Items. Moreover, the Measurement can be an ExpectedMeasurement (i.e. the value which is planned) or the ActualMeasurement (i.e. the value measured during production), which enables to check for deviations between the planned and actual values.
s4inma:ActualMeasurement	Describes whether the measurement is actually measured during the production process. Disjoint with ExpectedMeasurement.
s4inma:ExpectedMeasurement	Describes whether the measurement is expected (i.e. planned before the production process). Disjoint with ActualMeasurement.
s4inma:Measurement s4inma:hasFeatureOfInterest **only** (s4inma:Batch or s4inma:Item)	A relation between a certain measurement and the items or batches it relates to, i.e. an item or a batch can be the feature of interest of a measurement (inverse of s4inma:isFeatureOfInterestOf).

4.3 Instantiating SAREF4INMA

This clause further explains SAREF4INMA by showing an example instantiation, which is available at `http://ontology.tno.nl/examples/saref4inma/shaver.ttl`

This example instantiation is referred to using the `ex` prefix. This prefix is different from the `s4inma` prefix, which indicates the SAREF4INMA ontology on which the `ex` example instantiation is built upon.

The example is shown in Figure 6 and represents an instance of a shaver (i.e. the `ex:Shaver10023`) of the `s4inma:Item` class, which is an item created in a certain batch (represented by the `ex:PhilBrau_S40_Premium_Gold_Shaver_ItemBatch392` instance), which in turn belongs to a category of items called *PhilBrau S40 Premium Gold Shaver ItemCategory*. This item category is represented by the `ex:PhilBrau_S40_Premium_Gold_Shaver _ItemCategory` instance of the `s4inma:ItemCategory` class, it has model number `ex:nr98647656` and manufacturer `PhilBrau`, and is produced using a certain production equipment category, namely the `ex:Lazor_Series_8030_ProdEquipCategory` instance of the `s4inma:ProductionEquipmentCategory` class.

The `ex:Lazor_Series_8030_ProdEquipCategory` instance is the general category of a specific production equipment, namely the `ex:Laser_Cutting_Machine_1` instance of a laser cutting machine created specifically for this example (i.e. the `ex:LaserCuttingMachine` class created in this example as a subclass of the `s4inma:ProductionEquipment` class).

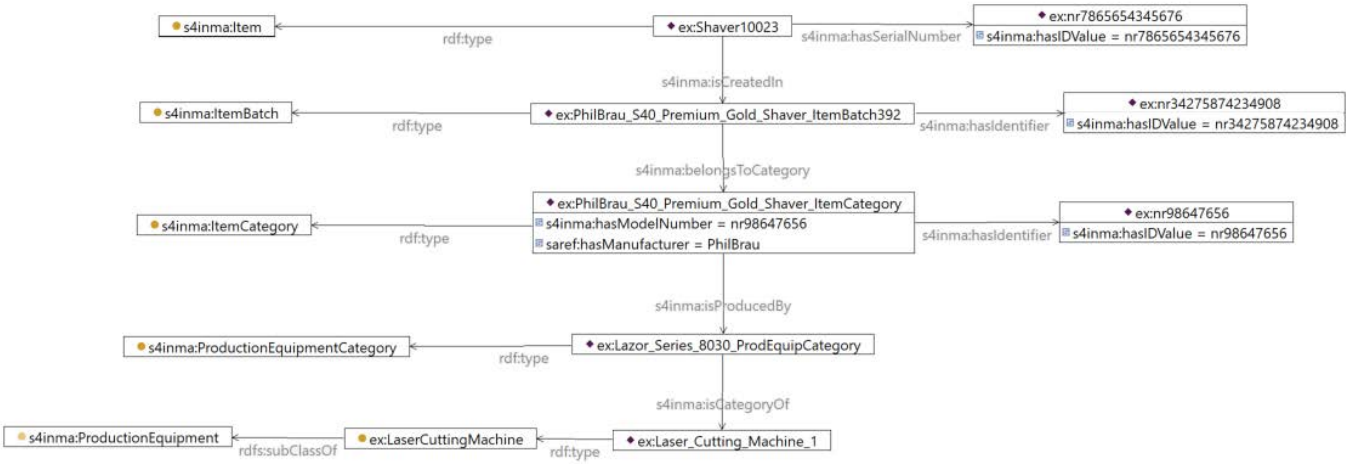

Figure 6: Item example

Figure 7 further shows that the *Shaver10023* item recursively consists of other three items, namely the *ShaverHead3002*, *StepMotor083* and *ShaverBody9440* items. In other words, SAREF4INMA allows to describe an item as a whole (i.e. the shaver) or in its parts (i.e. the shaver head, motor and body). The *ShaverBody9440* item is created in the *PhilBrau_S40-S50_Generic_Body_ItemBatch3290* item batch, which in turn consists of material from other batches, namely the *Torx screws D2mm L8mm MaterialBatch323* and *ABS Plastic Role 8mm MaterialBatch742*. These material batches belong to two different material categories classes created specifically for this example, respectively the `ex:Screw` class (with its `ex:Torx_screws_D2mm_L8mm_MaterialCategory` instance) and the `ex:Plastic` class (with its `ex:ABS_Plastic_Role_8mm_MaterialCategory` instance), which are both subclasses of `s4inma:MaterialCategory`. In other words, the body of a shaver is an item created in a batch that is made of other materials such as screws and plastic.

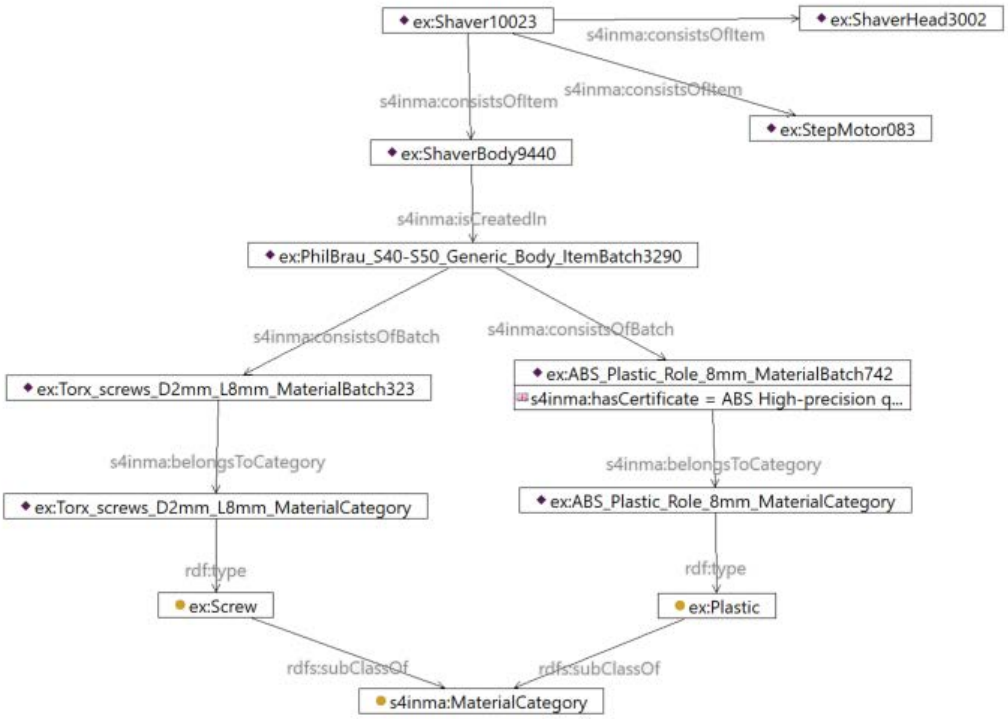

Figure 7: Material example

The example instantiation further defines two types of production equipment categories, namely the *Lazor_Series_8030_ProdEquipCategory* and the *WandI_Welding_Series_1000_ProdEquipCategory*. These categories represent a certain model of production equipment and not the individual machines, since an organization might have multiple machines of the same model. In particular, there is one laser cutting machine of type *Lazor_Series_8030_ProdEquipCategory*, namely the *Laser_Cutting_Machine_1*, and two welding machines, namely *Welding_Machine*_1 and *Welding_Machine_2*, which are shown in Figure 8.

These machines are instances of the `ex:WeldingMachine` and the `ex:LaserCuttingMachine` classes created for this example, which are both subclasses of the `s4inma:ProductionEquipment` class, which is in turn a subclass of `saref:Device`, which is in turn a subclass of `s4bldg:PhysicalObject`. The subclass relation of `saref:Device` ensures that a `s4inma:ProductionEquipment` can reuse SAREF functionality by inheritance, such as the possibility to perform functions, be composed by other devices such as sensors (e.g. temperature sensors), control properties (e.g. welding temperature) and make measurements. For example, the *Welding_Machine_2* production equipment can perform a *JoiningFunction* (`ex:JoiningFunction` class), controls the *WeldingTemperature* property, and further consists of the *Welding Machine Temperature Sensor 1*.

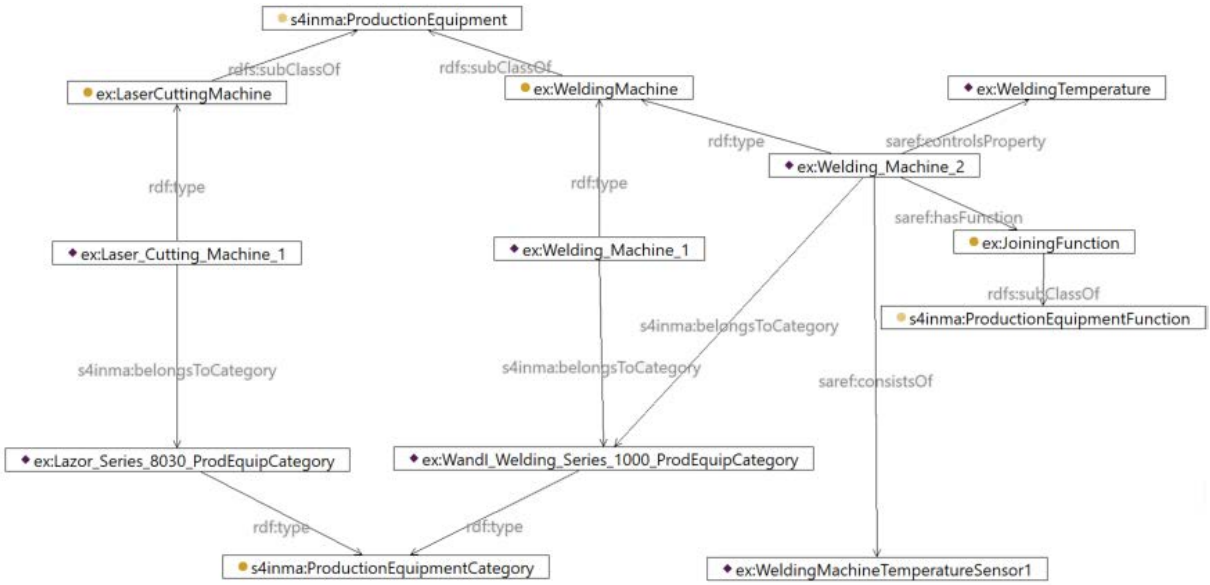

Figure 8: Production Equipment example

The *Welding Machine Temperature Sensor 1* makes some temperature measurements during the production of *Shaver 10023* in intervals of ten seconds. Figure 9 shows some example measurements related to the production of the *Shaver 10023* item and the reuse of the SAREF model for measurements. For example, the `ex:Welding_Machine_2_Measurement_W101520` instance is measured by the *WeldingMachineTemperatureSensor1*, relates to the *WeldingTemperature* property, has value *223* and unit of measure *degree Celsius*, has timestamp *2019-01-28T12:11:10* and has the item *Shaver10023* as feature of interest.

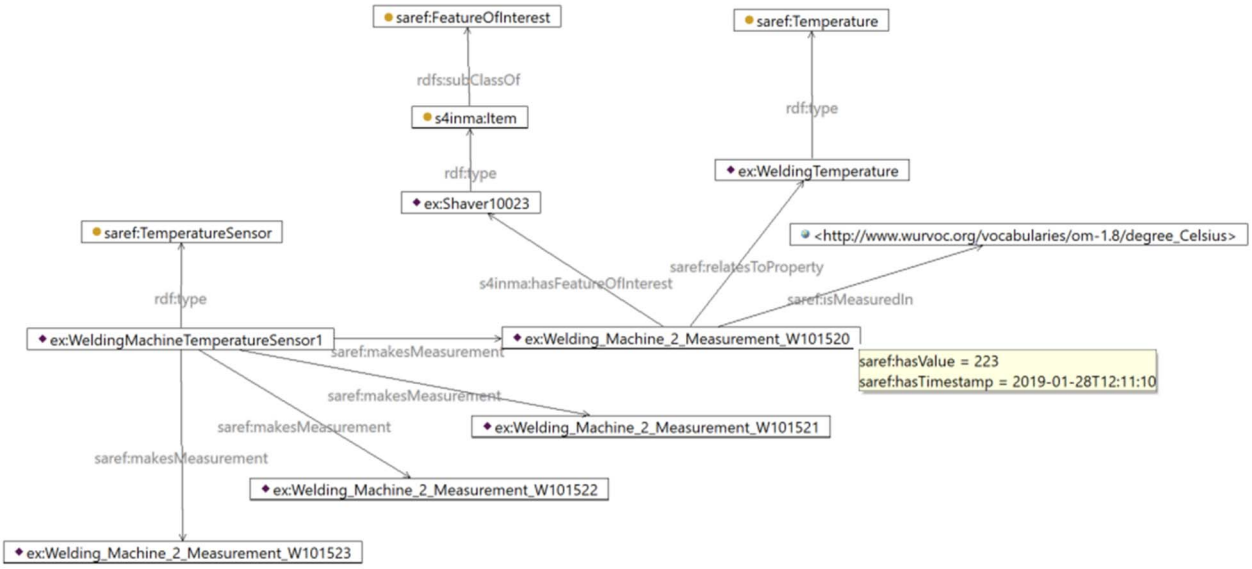

Figure 9: Measurement example

Since a `s4inma:ProductionEquipment` is a subclass of a `saref:Device` and consequently of `s4bldg:PhysicalObject`, it is possible to assign each production equipment instance to a physical location within the factory. Figure 10 shows an instance of a `s4inma:Factory` class, which in turn is defined in SAREF4INMA as a `s4bldg:Building` subclass. This instance (`ex:Eindhoven_BIC`) represents a factory that can be decomposed into *Site* and *Area*, building spaces, which are all subclasses of `s4bldg:BuildingSpaces`. Moreover, the welding machines and the laser cutting machine are part of the *Welding_WorkCenter*, which is a *WorkCenter* located in the *Area BIC Site A Area 19*, which is in its turn located in the *Site BIC Site A* in the *Eindhoven BIC* building.

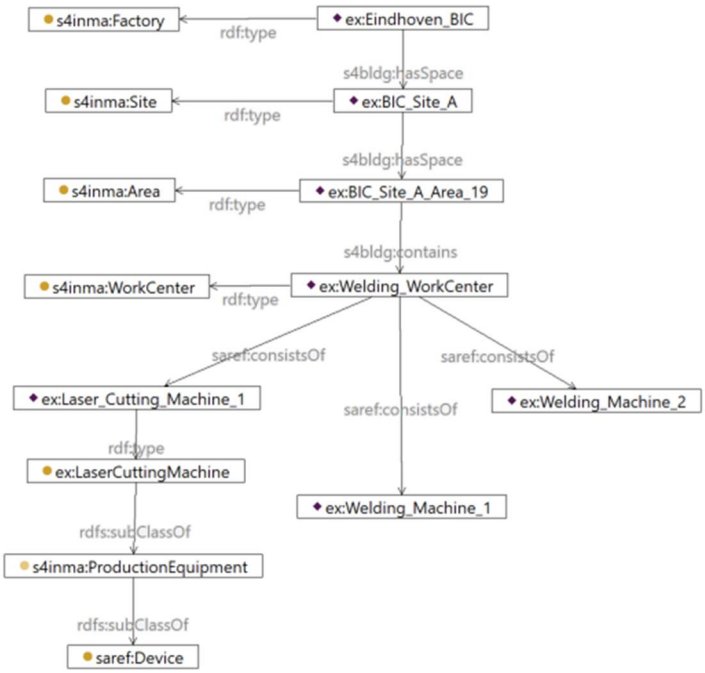

Figure 10: Factory example

Annex A (informative): Approach

To create the SAREF4INMA extension specified in the present document, a combination of bottom-up and top-down approaches was followed. First, the SAREF4INMA extension has been developed bottom-up from a set of requirements extracted from standards developed in the context of various initiatives in Europe that support digitalization in manufacturing (such as, for example, the platform Industrie 4.0 in Germany, the Smart Industry initiative in the Netherlands, Industria 4.0 in Italy, the Industrie du future initiative in France and more), as explained in the associated ETSI TR 103 507 [i.2]. Additionally, following a top-down approach, the SAREF4INMA extension development has been driven by already existing ontologies (i.e. SAREF and SAREF4BLDG) which define top concepts and relationships that needed to be extended for the industry and manufacturing domain.

Following the process defined in ETSI TR 103 411 [i.1], ontological engineers analysed the existing standards in the industry domain with the support of domain experts (the complete list of the analysed standards is detailed in [i.2]). Afterwards, an initial version of the ontological requirements for SAREF4INMA was proposed, which was then refined together with domain experts in order to obtain a stable version of the requirements. This refinement was carried out by means of on-line meetings.

As mentioned, SAREF and SAREF4BLDG concepts and properties have been reused and extended when they needed to be specialized.

The following classes and properties have been directly reused from SAREF:

- saref:Device.
- saref:Function.
- saref:Measurement.
- saref:Property.
- saref:consistsOf.
- saref:hasFunction.
- saref:makesMeasurement.
- saref:relatesToMeasurement.
- saref:isMeasuredIn.

The following classes and properties have been reused in SAREF4INMA to complete the model of measurements:

- `saref:FeatureOfInterest` to define the feature of interest being observed in a certain measurement.
- `saref:isPropertyOf` (and its inverse `saref:hasProperty`) to link the property being observed with the feature of interest.
- `saref:hasFeatureOfInterest` (and its inverse `saref:isFeatureOfInterestOf`) to link a given measurement with the feature of interest being observed.
- `saref:measurementMadeBy` as complement of the `saref:makesMeasurement`, as its inverse, to link a measurement and the device that produces it.

The following classes and properties have been directly reused from SAREF4BLDG:

- s4bldg:PhysicalObject.
- s4bldg:Building.
- s4bldg:BuildingSpace.
- s4bldg:hasSpace.

- s4bldg:isSpaceOf.
- s4bldg:contains.
- s4bldg:isContainedIn.

More precisely, the following classes have been extended with new SAREF4INMA classes:

- saref:Device and s4bldg:PhysicalObject have been extended with the s4inma:ProductionEquipment and s4inma:WorkCenter classes.
- saref:Function has been extended with the s4inma:ProductionEquipmentFunction class. Examples of these functions are defined in the SAREF4INMA instantiation in clause 4.3, i.e. ex:CuttingFunction, ex:FormingFunction and ex:JoiningFunction. Note that these functions provide only an initial example of how to reuse SAREF functions in the industry and manufacturing domain, but it is recommended that stakeholders in this domain further extend the s4inma:ProductionEquipmentFunction class as needed.
- saref:Property has been extended with s4inma:Size.
- s4bldg:BuildingSpace has been extended with s4inma:Site and s4inma:Area.

Finally, the Time ontology (http://www.w3.org/2006/time), which is already reused by SAREF, has also been reused in SAREF4INMA.

Annex B (informative): Bibliography

- ETSI TS 103 267: "SmartM2M; Smart Appliances; Communication Framework".
- ETSI TS 102 689: "Machine-to-Machine communications (M2M); M2M Service Requirements".

History

Document history		
V1.1.1	May 2019	Publication
V1.1.2	May 2020	Publication