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Automation systems and integration — Digital Twin framework for manufacturing — Part 3: Digital representation of manufacturing elements

DIS stage

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A model manuscript of a draft International Standard (known as "The Rice Model") is available at https://www.iso.org/iso/model_document-rice_model.pdf

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Foreword

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This document was prepared by Technical Committee ISO/TC 184, *Automation systems and integration*, Subcommittee SC 4, *Industrial Data*.

A list of all parts in the ISO 23247 series can be found on the ISO website.

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Introduction

ISO 23247 series defines a framework to support the creation of Digital Twins of observable manufacturing elements including personnel, equipment, materials, processes, facilities, environment, and products.

The scope of the four parts of this series are defined below:

- Part 1: Overview and general principles

  Provides an overview of Digital Twin for manufacturing, describes general principles, and provides requirements and guidance for developing a Digital Twin manufacturing framework;

- Part 2: Reference architecture

  Provides a reference architecture goals and objectives, reference model, and reference architectural views for a Digital Twin framework for manufacturing

- Part 3: Digital representation of manufacturing elements

  Identifies manufacturing elements of the Digital Twin framework for manufacturing that shall be represented in digital models;

- Part 4: Information exchange

  Identifies technical requirements for information synchronization and information exchange within the Digital Twin framework for manufacturing.

The types of manufacturing that can be supported by an implementation of the framework will depend on the technologies selected to implement its functional elements.

Use cases for Digital Twin framework for manufacturing will be detailed in a series of technical reports attached to this series.

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Automation systems and integration — Digital Twin framework for manufacturing — Part 3: Digital representation of manufacturing elements

1 Scope

This part of ISO 23247 identifies the observable manufacturing elements of the Digital Twin framework for manufacturing that shall be represented in digital models.

ISO 23247 series defines a framework to support the creation of Digital Twins of observable manufacturing elements including personnel, equipment, materials, processes, facilities, environment, and products.

The following are within the scope of this part of ISO 23247;

- Digital Twin of observable manufacturing element;
- Information for Digital Twin of Observable Manufacturing Elements.

The following are described in other parts of ISO 23247;

- overview and general principles (Part 1);
- reference architecture of the Digital Twin framework for manufacturing (Part 2);
- Information exchange (Part 4);
- use cases of the Digital Twin framework for manufacturing are to be detailed in technical reports.

The following are outside of the scope of ISO 23247;

- selection of the implementation methods and technologies for a Digital Twin for manufacturing;
- selection of the communication protocols for a Digital Twin for manufacturing;
- selection of the manufacturing devices and other resources to be represented by a Digital Twin;
- selection of the manufacturing processes to be represented by a Digital Twin;
- selection of the manufacturing products to be represented by a Digital Twin;
- design and process planning, and other non-manufacturing stages of the product lifecycle.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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ISO 23247-1, *Automation systems and integration — Digital Twin framework for manufacturing — Part 1: Overview and general principles*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 23247-1 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

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4 Digital Twin of observable manufacturing element

One of the Digital Twin functions is digital representation of observable manufacturing element. Figure 1 shows Digital Twin of observable manufacturing elements managed by Digital Twin Entity in Digital Twin framework for manufacturing reference architecture.

Digital Twin of observable manufacturing elements shall consider both static and dynamic information. Information fixed to an observable manufacturing element that does not change during manufacturing is classified as static information, whereas information that changes during manufacturing is classified as dynamic information. For example, the serial number of a machine is static. However, the amount or the shape of material during manufacturing processes can be dynamic.

For Digital Twin modelling of observable manufacturing elements, information associated with observable manufacturing elements shall be properly identified by Digital Twin Entity.

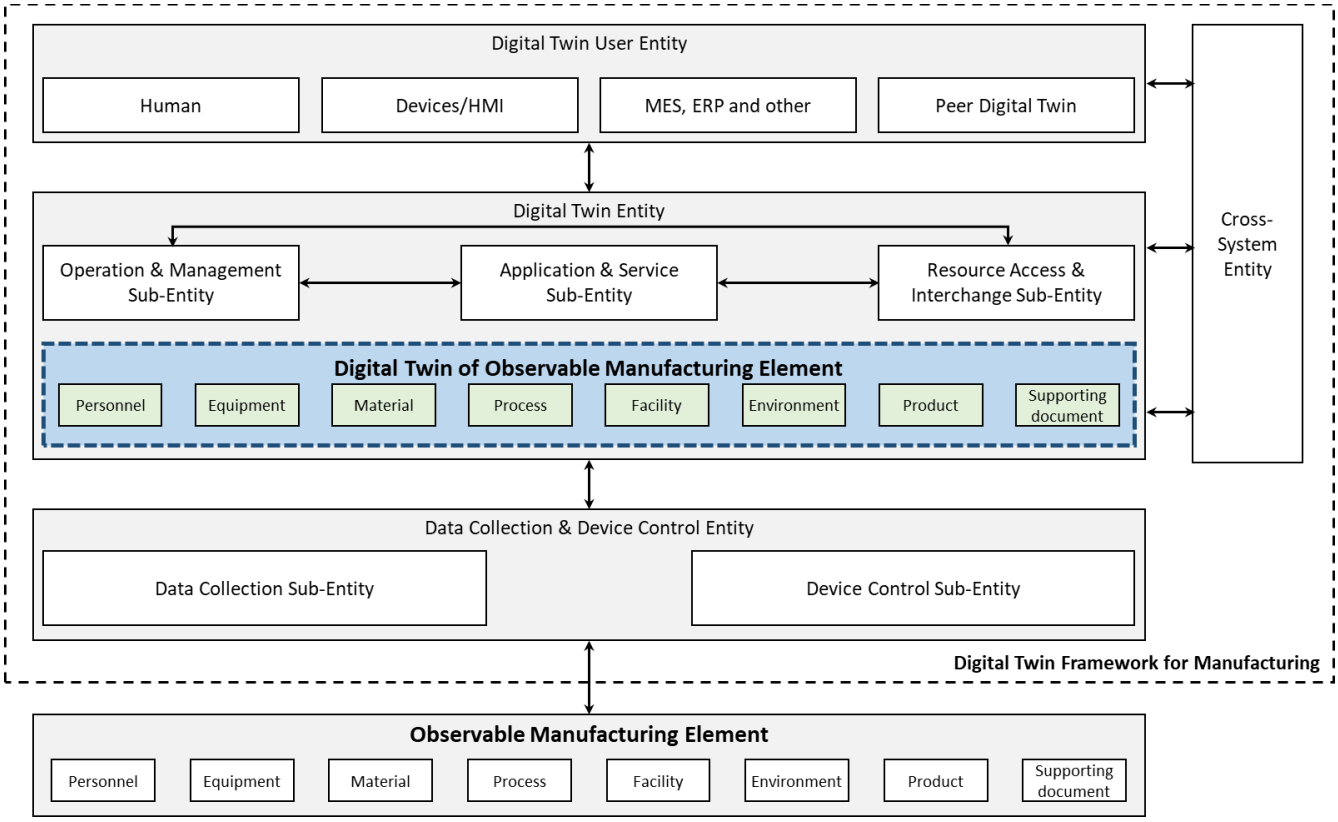

Figure 1 – Digital Twin of Observable Manufacturing Elements in reference architecture

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5 Information for Digital Twin of Observable Manufacturing Elements

5.1 Information attributes

As explained in Clause 4, a Digital Twin of an observable manufacturing element shall consider both static and dynamic features of information. In this document, these features are defined as information attributes.

The information attributes described in Figure 2 are examples to illustrate the kinds of information that should be represented for a Digital Twin. Many existing standards such as IEC 62264-2 and ISO 10303 contain detailed information models for these attributes. An implementation of the framework should select the information models most appropriate for its use case. Static information attribute includes identification, characteristics, schedule, relationship with other manufacturing elements, and description. Dynamic information attribute includes status, location, report, relationship with other manufacturing elements, and description.

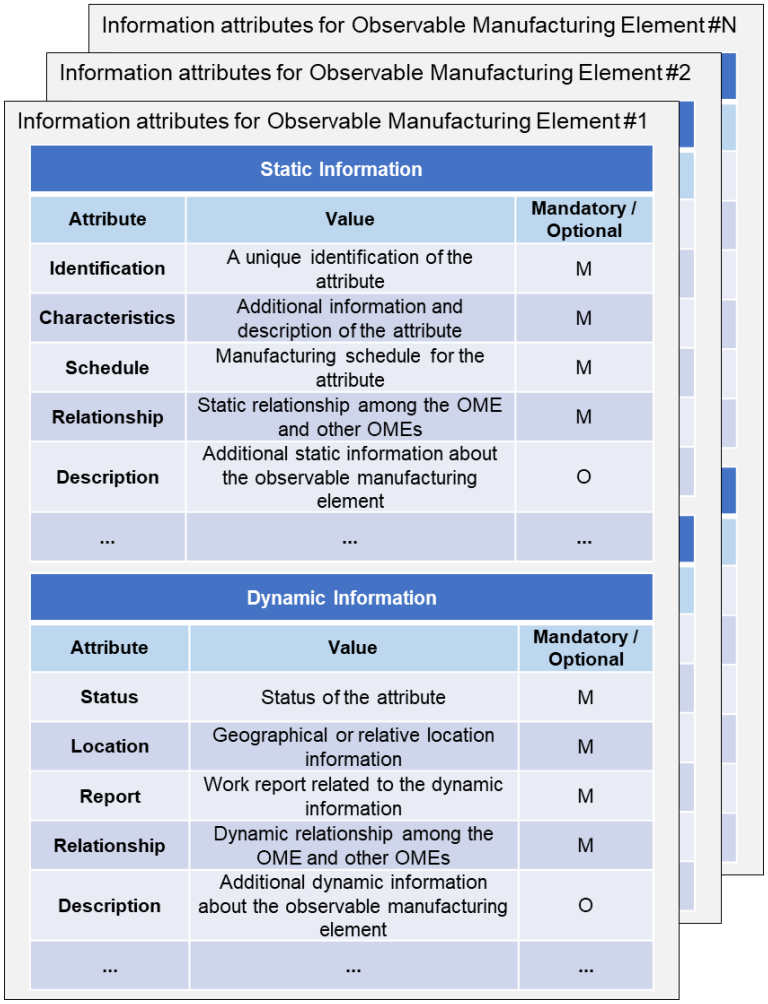

Figure 2– Information attributes for observable manufacturing elements

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5.2 Personnel

Personnel in manufacturing generally include those employees who are engaged directly or indirectly in manufacturing processes as described in ISO 23247-1. Static information of the personnel shall include identification, characteristics, schedule and relationship as shown in Table 1.

Table 1 – Static information of personnel

Attribute	Description	Examples
Identification	Information to identify personnel	· employee number
Characteristics	Classification of personnel	· skill · license · certification level · technician / engineer · senior / principal
Schedule	Working schedule for personnel	· working schedule
Relationship	Static relationship for personnel and other manufacturing elements	· Person #1 is the boss of Person #2
Description	Additional information and explanation about the static information of personnel	· general information about an employee

The values of dynamic information of personnel are changed during manufacturing processes. Dynamic information of personnel shall include status, location, report and relationship as shown in Table 2.

Table 2 – Dynamic information of personnel

Attribute	Description	Examples
Status	Status of personnel	· working / paused
Location	Location information (geographical / relative location)	· Person #1: WorkUnit #3 and 50 cm away from Robot #2
Report	Work report related to personnel	· May 14th 2019: Some hours of work
Relationship	Dynamic relationship for personnel and other manufacturing elements	· Person #1 and Person #2 are working in the WorkUnit #3 · Person #1 and Person #2 are 70 cm away from Machine #2.
Description	Additional information and explanation about the dynamic information of personnel	· dynamic information of personnel changing during manufacturing processes

NOTE 1 Some working place must have the required minimum personnel for safety reasons.

NOTE 2 Various kinds of devices are available to detect the identifier, location, motion, and image of observable manufacturing elements.

NOTE 3 Performance may be calculated and represented for manufacturing elements.

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5.3 Equipment

Equipment is a physical element that carries out an operation that is directly or indirectly involved in manufacturing processes as described in ISO 23247-1. Static information of equipment are shown in Table 3.

Table 3 –Static information of equipment

Attribute	Description	Examples
Identification	Information to identify equipment	· serial number
Characteristics	Classification of equipment	· milling · turning · grinding · pressing
Schedule	Working schedule for equipment	· working schedule · maintenance schedule
Relationship	Static relationship for equipment and other manufacturing elements	· Machine #1 operates with Material #2.
Description	Additional information and explanation about the static information of equipment	· general information about equipment

The values of dynamic information of equipment are changed during manufacturing processes. Dynamic information of equipment are shown in Table 4.

Table 4 – Dynamic information of equipment

Attribute	Description	Examples
Status	Status of equipment	· on / off · working / breakdown · performance (energy usage, output) · temperature, pressure, sound / noise
Location	Location information (geographical / relative location)	· Machine #2: WorkUnit #2 in Room #3
Report	Work report related to equipment	· May 14th, 2019 9 AM to 6 PM: Regular Maintenance · May 14th, 2019 11 AM: Machine #1 reports high temperature.
Relationship	Dynamic relationship for equipment and other manufacturing elements	· Machine #1 is operated by Person #2 in WorkCenter #5.
Description	Additional information and explanation about the dynamic information of equipment	· dynamic information of equipment changing during manufacturing processes

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5.4 Material

Material is physical matter that becomes a part or the whole of a product i.e., metal block, glass panel, etc., or is used to aid manufacturing processes, i.e., cleaning fluid, coolant, etc. as described in ISO 23247-1. Static information of material shall include identification, characteristics, schedule and relationship as shown in Table 5.

Table 5 – Static information of material

Attribute	Description	Examples
Identification	Information to identify material	· bar code · RFID tag
Characteristics	Classification of material	· handle with care / fragile · toxic · liquid / solid / gas · plastic / steel / rubber / powder
Schedule	Working schedule for material	· input schedule · purchase schedule · inbound / outbound schedule
Relationship	Static relationship for material and other manufacturing elements	· Material #1 shall be managed by person with Skill #2.
Description	Additional information and explanation about the static information of material	· general information about material

The values of dynamic information of material are changed during manufacturing processes. Dynamic information of material shall include status, location, report and relationship as shown in Table 6.

Table 6 – Dynamic information of material

Attribute	Description	Examples
Status	Status of material	· Tested · Availability · liquid / solid / gas
Location	Location information (geographical / relative location)	· Material #1: Shelf #3 in Warehouse #2
Report	Work report related to material	· May 14th, 2019: 8 kg of Material #2 is used in WorkUnit #2
Relationship	Dynamic relationship for material and other manufacturing elements	· Material #1 is operated by a person with Skill #2 in WorkCenter #5.
Description	Additional information and explanation about the dynamic information of material	· dynamic information of material changing during manufacturing processes

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5.5 Process

A process is an observable physical operation within manufacturing as described in ISO 23247-1. Static information of the process shall include identification, characteristics, schedule and relationship as shown in Table 7.

Table 7 – Static information of process

Attribute	Description	Examples
Identification	Information to identify process	· process identifier
Characteristics	Classification of process	· production / maintenance / quality test / inventory · milling / drilling · additive
Schedule	Working schedule for process	· periodic, one time, limit, duration
Relationship	Static relationship for process and other manufacturing elements	· ManufacturingProcess #1 is managed by a person with Skill #3.
Description	Additional information and explanation about the static information of process	· general information about process

The values of dynamic information of process are changed during manufacturing processes. Dynamic information of process shall include status, location, report and relationship as shown in Table 8.

Table 8 – Dynamic information of process

Attribute	Description	Examples
Status	Status of process	· planned · in-process · finished / incomplete
Location	Location information (geographical / relative location)	· Process #1: Machine #2 in Room #3
Report	Work report related to the process	· May 14th, 2019: Machine #2 completed MillingOperation #5.
Relationship	Dynamic relationship for process and other manufacturing elements	· MillingOperation #1 is operated by Person #3 with Skill #2 in WorkCenter #3.
Description	Additional information and explanation about the dynamic information of process	· dynamic information of process changing during manufacturing processes

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5.6 Facility

Facility is infrastructure that is related to or affects manufacturing as described in ISO 23247-1. Static information of the facility shall include identification, characteristics, schedule and relationship as shown in Table 9.

Table 9 – Static information of facility

Attribute	Description	Examples
Identification	Information to identify facility including environment, energy, etc.	· serial number · asset number
Characteristics	Classification of facility	· air-conditioning / ventilating
Schedule	Working schedule for facility	· periodic, one time, limit, duration
Relationship	Static relationship for facility and other manufacturing elements	· Facility #1 is controlled by a person with Skill #3 when the temperature exceeds the limits.
Description	Additional information and explanation about the static information of facility	· general information about facility

NOTE Some facilities do not have identification, such as doors.

The values of dynamic information of facility are changed during manufacturing processes. Dynamic information of facility shall include status, location, report and relationship as shown in Table 10.

Table 10 – Dynamic information of facility

Attribute	Description	Examples
Status	Status of facility	· Normal / abnormal
Location	Location information (geographical / relative location)	· Facility #2: Room #3
Report	Work report related to facility	· May 14th, 2019 9 AM: Facility #2 reports alarm of high temperature. · May 14th, 2019 10 AM: Person #3 turned on the #Facility 3(air conditioner).
Relationship	Dynamic relationship for facility and other manufacturing elements	· Machine #3 is using Facility (air conditioner) #2 for MillingOperation #3 in Room #2 to be kept at 20 °C.
Description	Additional information and explanation about the dynamic information of facility	· dynamic information of facility changing during manufacturing processes

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5.7 Environment

Environment is necessary condition that shall be supplied by facilities for the correct execution of a manufacturing process as described in ISO 23247-1. Static information of the environment shall include identification, characteristics, schedule and relationship as shown in Table 11.

Table 11 – Static information of environment

Attribute	Description	Examples
Identification	Information to identify environment including time and location.	· Combination of time, sensor ID and sensor value · Combination of time and energy consumption (kWh)
Characteristics	Classification of environment	· temperature / humidity / illuminance
Schedule	Working schedule for environment	· periodic, one time, limit, duration
Relationship	Static relationship for environment and other manufacturing elements	· Room #2 should be kept at 20 °C while manufacturing is being performed.
Description	Additional information and explanation about the static information of environment	· general information about environment

NOTE Some environment does not have identification, such as temperature, humidity, and illumination. Environment data has the meaning associated with the time and location.

The values of dynamic information of environment are changed during manufacturing processes. Dynamic information of environment shall include status, location, report and relationship as shown in Table 12.

Table 12 – Dynamic information of environment

Attribute	Description	Examples
Status	Status of environment	· Normal / abnormal
Location	Location information (geographical / relative location)	· May 14th, 2019 10 AM: temperature #2 is 25 °C in Room #3.
Report	Report related to environment	· May 14th, 2019 9 AM: Room #2 reports alarm of high temperature that the temperature #2 is 30 °C.
Relationship	Dynamic relationship for environment and other manufacturing elements	· May 14th, 2019 10 AM: Person #3 turned on the #Facility 3(air conditioner) to lower Temperature #2 to 20 °C.
Description	Additional information and explanation about the dynamic information of environment	· dynamic information of environment changing during manufacturing processes

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5.8 Product

Product is a desired output or by-product of manufacturing process as described in ISO 23247-1. Static information of the product shall include identification, characteristics, schedule and relationship as shown in Table 13.

Table 13 – Static information of product

Attribute	Description	Examples
Identification	Information to identify product	· product model · serial number
Characteristics	Classification of product	· dimensions · colour
Schedule	Working schedule for product	· periodic, one time, limit, duration
Relationship	Static relationship for product and other manufacturing elements	· Product #1 is produced by Machine #3.
Description	Additional information and explanation about the static information of product	· general information about product

The values of dynamic information of product are changed during manufacturing processes. Dynamic information of product shall include status, location, report and relationship as shown in Table 14.

Table 14 – Dynamic information of product

Attribute	Description	Examples
Status	Status of product	· in-process · 300 of 312 fasteners presently installed · finished · inventory
Location	Location information (geographical / relative location)	· Product #2: Warehouse #3
Report	Work report related to product	· May 14th, 2019 9 AM: Product #2 has passed QualityTest #5. · May 14th, 2019 10 AM: Product #2 has moved to Warehouse #3.
Relationship	Dynamic relationship for product and other manufacturing elements	· Product #3 is in process by Machine #2 for MillingOperation #3.
Description	Additional information and explanation about the dynamic information of product	· dynamic information of product changing during manufacturing processes

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5.9 Supporting document

A supporting document is any form of artefact that helps the applications of Digital Twin for manufacturing as described in ISO 23247-1. Static information of the supporting document shall include identification, characteristics, schedule and relationship as shown in Table 15.

Table 15 – Static information of supporting document

Attribute	Description	Examples
Identification	Information to identify supporting document	· document type · document number
Characteristics	Classification of supporting document	· requirement · plan · model · specification · configuration
Schedule	Working schedule for supporting document	· periodic, one time, limit, duration
Relationship	Static relationship for supporting document and other manufacturing elements	· May 12th, 2019 10 AM: Person #3 produced SupportingDocument #2.
Description	Additional information and explanation about the static information of supporting document	· general information about supporting document

The values of dynamic information of supporting document are changed during manufacturing processes. Dynamic information of supporting document shall include status, location, report and relationship as shown in Table 14.

Table 16 – Dynamic information of supporting document

Attribute	Description	Examples
Status	Status of supporting document	· planned · in-process · finished / incomplete
Location	Location information (geographical / relative location)	· SupportingDocument #2: Directory #3
Report	Work report related to supporting document	· May 14th, 2019 9 AM: Person #2 has stored SupportingDocument #2 in the Directory #5. · May 14th, 2019 10 AM: Person #3 has moved SupportingDocument #2 to Directory #3.
Relationship	Dynamic relationship for supporting document and other manufacturing elements	· Person #3 is planning to produce SupportingDocument #3 for DrillingOperation #5 by May 31th, 2019.

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Description	Additional information and explanation about the dynamic information of supporting document	· dynamic information of supporting document changing during manufacturing processes

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Annex A
(informative)

Existing technologies for representing manufacturing elements

Existing standards and specifications, including ISO 10303 series, IEC 62264 series, IEC 62714 series, ISO 13399 series, and eCl@ss can be used to represent manufacturing elements.

ISO 10303, known as Standard for the Exchange of Product Model Data (STEP), series define the computer-interpretable representation of product information and the exchange of product and process data [1] [2]. The objective of ISO 10303 series is to provide a neutral mechanism capable of describing products and their manufacturing processes throughout their life cycle. This mechanism is appropriate not only for neutral file exchange, but also as a basis for implementing and sharing product databases, and as a basis for archiving. STEP series are used for data exchange among CAD/CAM systems and between CAD/CAM and manufacturing systems. The information models for ISO 10303 series are described using EXPRESS schemas.

ISO 10303-238 specifies an application protocol (AP) for numerically controlled machining and associated processes. ISO 10303-238 includes the information requirements defined by the ISO 14649 series data model for numerical controllers, augmented with product geometry, geometric dimensioning and tolerancing, and product data management information [1].

ISO 10303-239 specifies the application protocol for product life cycle support. The scope of ISO 10303-239 includes information for defining and maintaining a complex product, and information required for through life configuration change management of a product and its support solution. Also, it includes representation of product assemblies, product through life, specification and planning of activities for a product, the activity history of a product and product history.

ISO 10303-242 specifies the application protocol for managed model-based 3D engineering [12]. The scope of ISO 10303-242 includes products of automotive, aerospace and other mechanical manufacturers and of their suppliers, engineering and product data, product data management, process planning, mechanical design, kinematics, geometric definition and tolerancing and composite design [2]. The ISO 10303 series can be used to define information models and 3D engineering for manufacturing elements.

IEC 62264 series are based on ISA-95 [3] [4]. IEC 62264 series and provide consistent terminology that is a foundation for supplier and manufacturer communications. IEC 62264 series also provide consistent information models and object models to integrate control systems with enterprise systems that improve communications among all manufacturing elements involved. B2MML is an XML implementation of the IEC 62264 series, Enterprise-Control System Integration [5]. B2MML consists of a set of XML schemas written using the World Wide Web Consortium's XML Schema language (XSD) that implement the data models in the IEC 62264 series.

IEC 62714 series, known as Automation Markup Language (AML), describe the data exchange format using XML schema [6]. AML has been developed to support the data exchange and interconnect in heterogeneous engineering tools in their different disciplines. IEC 62714 series can be used to represent data exchange format among manufacturing elements.

ISO 13399 series describe the computer-interpretable representation and exchange of industrial product data about cutting tools and tool holders [7]. ISO 13399 series defines the reference dictionary for cutting items, tool items, adaptive items, etc. ISO 13399 series can be used to represent and exchange data for cutting tools.

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The eCl@ss (classification and production description) defines tens of thousands of product classes and unique properties including procurement, storage, production and distribution activities [8]. The eCl@ss can be used to define classes and properties for manufacturing elements conformant to IEC 61360 and ISO 13854-42.

The asset administration shell is part of the I4.0 component as introduced in IEC PAS 63088. It provides a technology neutral information model and several serializations and mapping. The asset administration shell is one possible concept and specification that can used to implement twins. Serializations and mappings are provided for XML, JSON, RDF, AutomationML and OPC UA. One of its key features is the separation of the digital representation into a set of so-called submodels. Each submodel represents a specific aspect of the asset the twin is representing.

IEC 62541 (OPC UA) represents the international standard of OPC UA, which is for vertical and horizontal communication in manufacturing and automation, providing semantic interoperability for the world of connected systems [9]. It has been designed for scalability and supports a wide range of application domains, ranging from field level (e.g. devices for measurement or identification, PLCs), to enterprise management support. New information models of elements for Digital Twin in manufacturing can be created based on the OPC UA Data Model and eventually derived from OPC UA Base Information Models.

New information models, based on the OPC UA data model, can be created and eventually derived from OPC UA base information models. The specifications of such Information Models, called Companion Specifications, are regarded as “Industry standard models” because they typically address a dedicated industry problem. The synergy of the OPC UA infrastructure to exchange such industry information models enables interoperability at the semantic level.

The MTConnect standard (ANSI/MTC1.4-2018) provides a semantic vocabulary for manufacturing equipment to provide structured, contextualized data with no proprietary format [10]. With uniform data by MTConnect standard, developers and integrators can focus on useful, productive manufacturing applications rather than translation. MTConnect data offer more efficient operations, improved production optimization, and increased productivity.

QIF (Quality Information Framework) is standardized as an American National Standard supporting Digital Thread concepts in engineering applications ranging from product design through manufacturing to quality inspection [11]. The XML-based QIF standard contains a library of XML schema ensuring both data integrity and data interoperability in Model Based Enterprise implementation.

RDF is a standard model for data interchange on the Web [12]. RDF has features that facilitate data merging even if the underlying schemas differ, and it specifically supports the evolution of schemas over time without requiring all the data consumers to be changed.

Each technology has its characteristics for digital representation of manufacturing elements. Digital Twin developers should carefully consider which should be used for the target applications.

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Annex B
(informative)

Example of Business To Manufacturing Markup Language (B2MML)

Figure B.1 shows how a B2MML Product Definition document can be embedded into an MTConnect Asset [9] to create a B2MML Product Definition Asset type defined by MTCUP (http://www.mtcup.org/wiki/B2MML) [13].

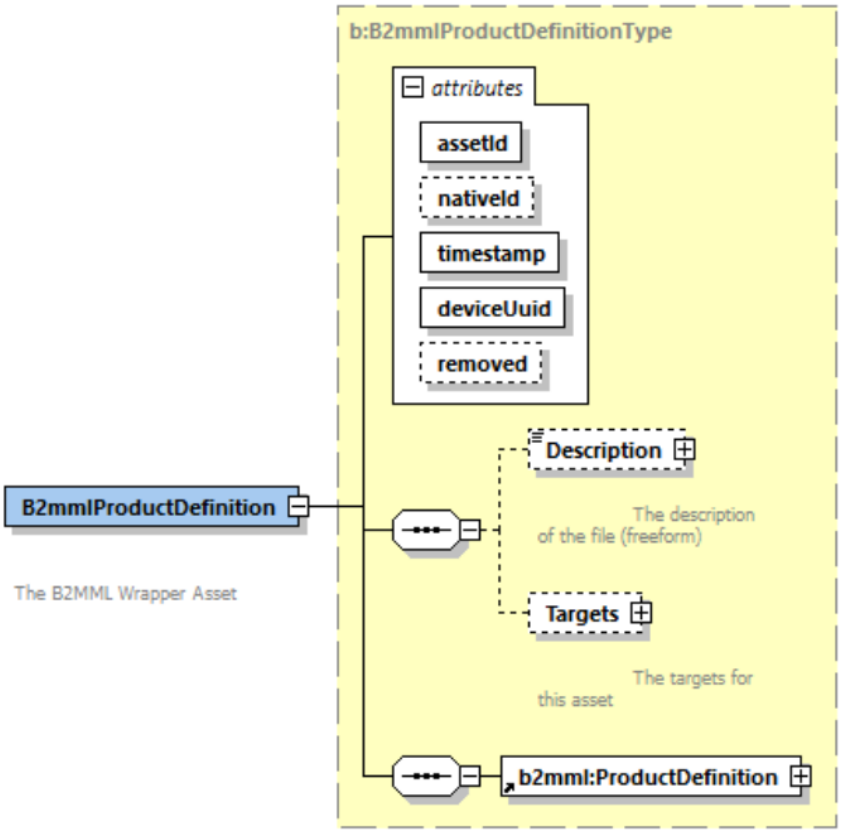

Figure B.1 B2MML product definition type [13]

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The resulting MTConnect Assets document including a B2MML Product Definition type Asset is described as follows: [13]

```
<?xml version="1.0" encoding="UTF-8"?>
<MTConnectAssets xsi:schemaLocation="urn:mtconnect.org:B2MML:1.3/schemas/B2MML_1.3.xsd"
    xmlns:b="urn:mtconnect.org:B2MML:1.3"
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xmlns="urn:mtconnect.org:MTConnectAssets:1.3"
    xmlns:m="urn:mtconnect.org:MTConnectAssets:1.3">
    <Header assetCount="132" assetBufferSize="10240" version="1.4.0.3"
     instanceId="1505504796" sender="ubuntu" creationTime="2017-10-12T13:50:35Z"/>
    <Assets>
       <B2mmlProductDefinition assetId="9ede2e6c-f2f2-55fb-ab60-f7ae2a21ad17"
        deviceUuid="itamco_Haas_1c2bc0" timestamp="2017-09-15T19:46:49.679251Z">
              <ProductDefinition
                     xmlns="http://www.mesa.org/xml/B2MML-V0600">
                     <ID>TEST-00003 </ID>
                     <Description>Base, Part 1a, Rev. - Base, Part 1a</Description>
                     <ProductSegment>
                            <ID>TEST-00003 </ID>
                     </ProductSegment>
              </ProductDefinition>
       </B2mmlProductDefinition>
       <B2mmlProductDefinition assetId="42078e08-169a-5183-ad38-78f2daa0593c"
        deviceUuid="itamco_Haas_1c2bc0" timestamp="2017-09-15T19:46:49.242110Z">
              <ProductDefinition xmlns="http://www.mesa.org/xml/B2MML-V0600">
                     <ID>TEST-00004 </ID>
                     <Description>Rear Mount, HV, Left, Rev. - Rear, HV, Mount,
                       Left</Description>
                     <ProductSegment>
                            <ID>TEST-00004</ID>
                     </ProductSegment>
              </ProductDefinition>
       </B2mmlProductDefinition>
    </Assets>
</MTConnectAssets>
```

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[2] ISO 10303-242, *Industrial automation systems and integration — Product data representation and exchange — Part 242: Application protocol: Managed model-based 3D engineering*

[3] IEC 62264-1, *Enterprise-control system integration – Part 1: Models and terminology*

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