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Automation systems and integration — Digital Twin framework for manufacturing — Part 2: Reference architecture

DIS stage

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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, products, and supporting documents.

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 framework for manufacturing;

– 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.

Automation systems and integration — Digital Twin framework for manufacturing — Part 2: Reference architecture

1 Scope

This part of ISO 23247 provides a reference architecture of Digital Twin for manufacturing.

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

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

- reference architecture goals and objectives,
- reference model, and
- reference architectural views

The following are described in other parts of ISO 23247;

- overview and general principles (Part 1)
- digital representation of manufacturing elements of the Digital Twin framework for manufacturing (Part 3);
- information exchange of the Digital Twin framework for manufacturing (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.

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

ISO/IEC 30141, *Internet of Things (IoT) — Reference architecture*

3 Terms and definitions

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

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

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

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

3.1
observable manufacturing domain
spatial/logical/functional area of the observable manufacturing resources

EXAMPLE Spatial/logical/functional area of machine tool

3.2
data collection and device control domain
spatial/logical/functional area of monitoring and collecting data from observable manufacturing domain, and controlling devices in observable manufacturing domain

EXAMPLE Spatial/logical/functional area of machine tool controller

3.3
data collection and device control entity
(a set of) system(s) or device(s) providing data collection and device control in data collection and device control domain

3.4
Digital Twin domain
spatial/logical/functional area of overall operation and management of Digital Twin including provisioning, managing, monitoring, and optimization

EXAMPLE Spatial/logical/functional area of Digital Twin server implementing Digital Twin management, simulation, authentication, and authorization

3.5
Digital Twin system entity
set of sub-systems providing functionalities for Digital Twins such as realisation, management, synchronization and simulation

3.6
Digital Twin user domain
spatial/logical/functional area using applications and services provided in the Digital Twin domain

3.7
Digital Twin user entity
system(s) that uses applications and services provided in the Digital Twin system entity

4 Digital Twin reference architecture for manufacturing goals and objectives

Digital Twin reference architecture for manufacturing defines reference models and architectural views.

Digital Twin reference architecture for manufacturing provides guidance for managing Digital Twins in manufacturing. The architecture increases understanding of Digital Twins for stakeholders including device manufacturers, application developers, users, etc.

The Digital Twin architecture uses the Internet of Things (IoT) as its defining technology. ISO/IEC 30141 defines the IoT reference models to include a domain-based reference model and an entity-based reference model. It also defines reference architectural views including a functional view, a system deployment view, a networking view, and a usage view.

This document includes the following descriptions in addition to those contained in ISO/IEC 30141:

– Digital Twin reference models for manufacturing, describing structure of the domains and structure of the entities;

– a set of relevant architectures in terms of functional and networking views

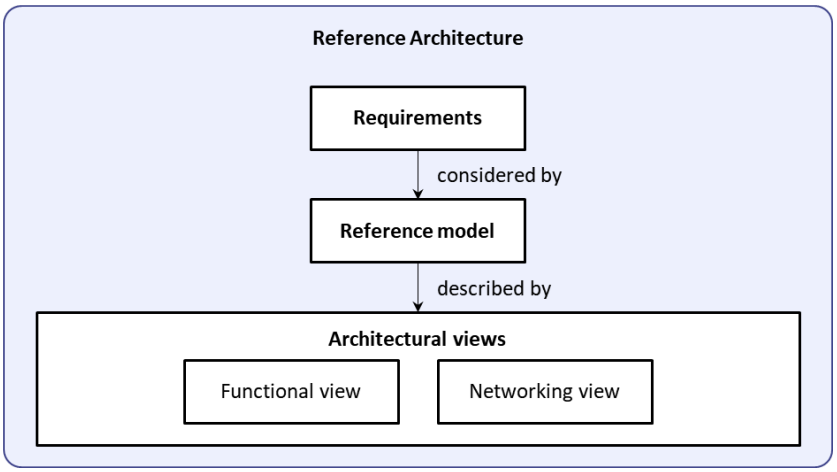

Figure 1 – Outline of Digital Twin reference architecture for manufacturing

Figure 1 shows outline of Digital Twin reference architecture for manufacturing to define relevant reference models and architectural views derived from requirements specified in ISO 23247-1.

5 Digital Twin reference models for manufacturing

5.1 Domain-based reference model

5.1.1 Domains of Digital Twin for manufacturing

Figure 2 shows a domain-based reference model of Digital Twin for manufacturing. Domain-based reference model is useful to describe various tasks that have to be performed in separate areas, by allowing a logical and sometimes physical subdivision. In other words, domains are used to sort functions into areas of responsibility.

In Digital Twin for manufacturing, domains are classified into four categories as follows:

– Digital Twin user domain
– Digital Twin domain
– data collection and device control domain
– observable manufacturing domain

Observable manufacturing domain is out of scope of Digital Twin for manufacturing, however, this document describes observable manufacturing domain to enhance understanding of Digital Twin for manufacturing.

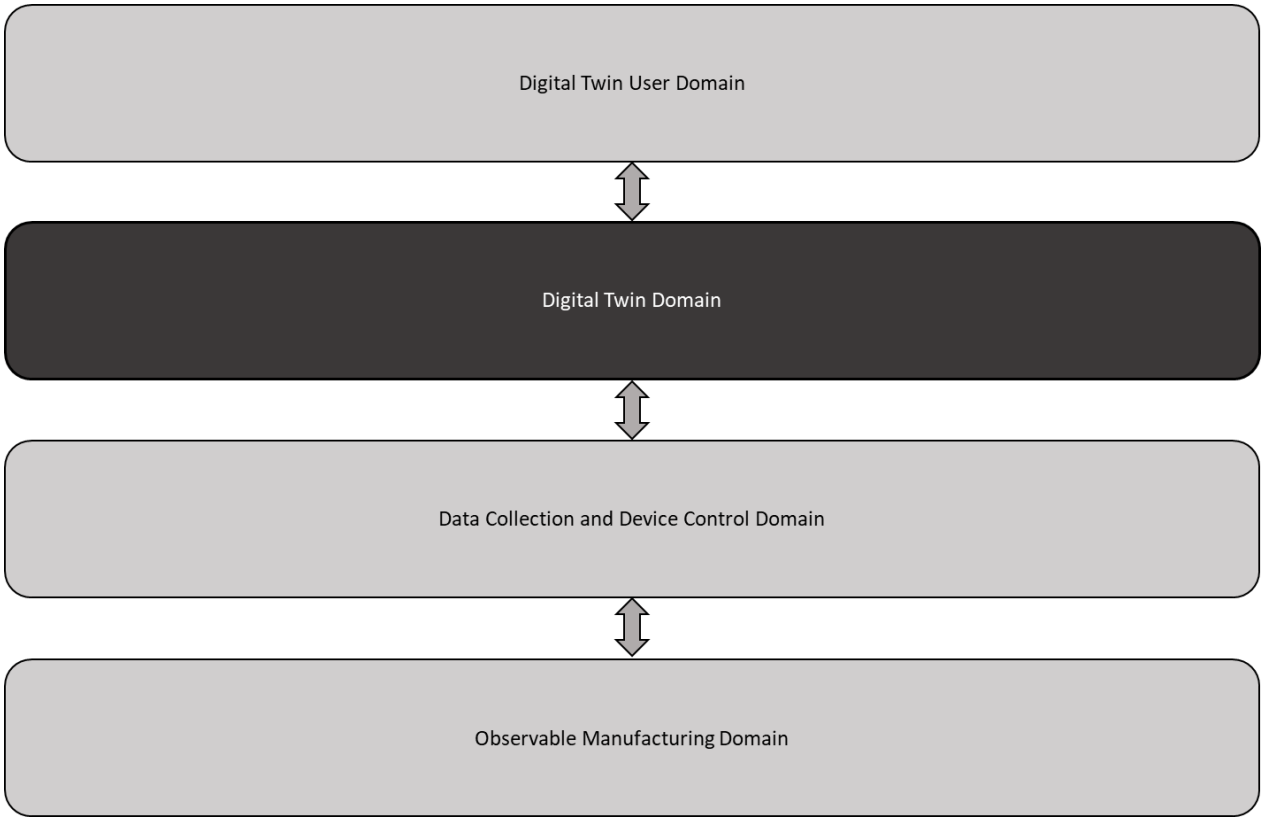

Figure 2 – Domain-based Digital Twin reference model for manufacturing

This classification is a logical grouping of tasks and functions, which are performed by the functional entities (FE) explained in 6.2. Entities in a domain interact with other entities in other domains by means of a set of networks described in 6.3.

206 ### 5.1.2 Observable manufacturing domain

207 Observable manufacturing domain consists of the physical manufacturing resources such as personnel,
208 equipment, material, process, facility, and environment. Observable manufacturing domain shall be
209 monitored and sensed for data collection and device control in Digital Twin for manufacturing.

210 ### 5.1.3 Data collection and device control domain

211 Data collection and device control domain monitors and collects data from sensory devices in
212 observable manufacturing domain, and control and actuate devices in observable manufacturing
213 domain. Data collection and device control domain links observable manufacturing elements and digital
214 entities for synchronization.

215 ### 5.1.4 Digital Twin domain

216 Digital Twin domain is responsible for overall operation and management of Digital Twin for
217 manufacturing including provisioning, managing, monitoring, and optimization. In detail, digital
218 modeling, presentation, and synchronization of observable manufacturing element are done in Digital
219 Twin domain.

220 Digital Twin domain hosts the applications and services such as simulation, analysis, etc. In addition,
221 Digital Twin domain provides access to entities of Digital Twin for manufacturing and interaction with
222 external entities such as peer Digital Twin domain by guaranteeing interoperability.

223 ### 5.1.5 Digital Twin user domain

224 In Digital Twin for manufacturing, a user can be a person, a device, or a system who uses applications
225 and services provided by Digital Twin domain.

226 ## 5.2 Entity-based reference model

227 ### 5.2.1 Entities of Digital Twin for manufacturing

228 Entity-based reference model breaks down Digital Twin for manufacturing into system level in
229 conjunction with the domain concept, which helps to understand system composition of Digital Twin
230 for manufacturing.

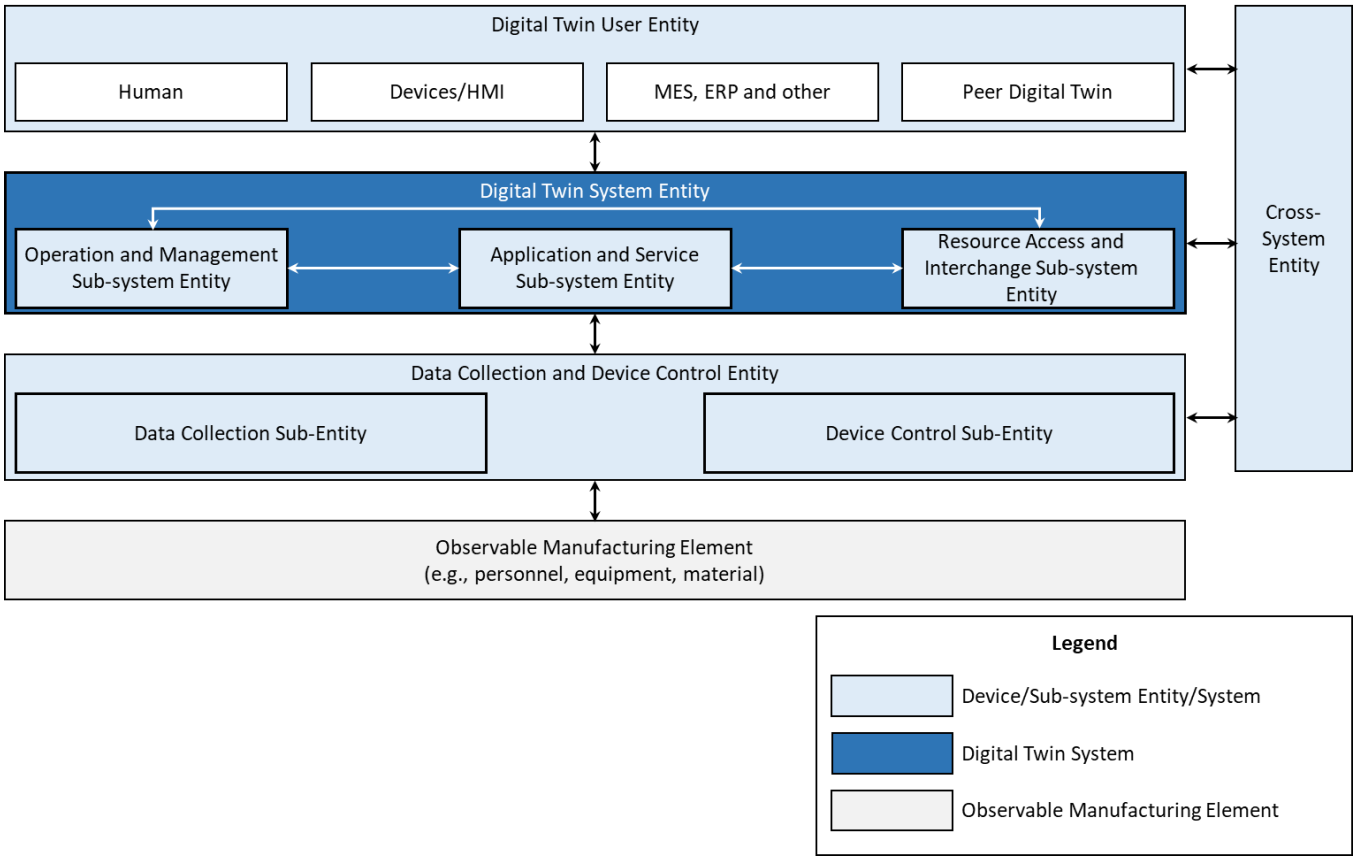

Figure 3 – Entity-based Digital Twin reference model for manufacturing

Figure 3 shows an entity-based Digital Twin reference model for manufacturing. A set of operation and management sub-system entity, application and service sub-system entity, and resource access and interchange sub-system entity digitally represents observable manufacturing elements as Digital Twins, and maintains the Digital Twins, therefore it is called Digital Twin system entity.

5.2.2 Observable manufacturing element

Observable manufacturing element shall be monitored and sensed, and may be actuated and controlled by data collection and device control entity. It includes personnel, equipment, material, process, etc.

5.2.3 Data collection and device control entity

5.2.3.1 General

Digital Twin shall have one or more data collection and device control entity, because Digital Twin consists of one or more observable manufacturing elements that shall be controlled.

5.2.3.2 Data collection sub-entity

Data collection sub-entity interacts with the observable manufacturing element by collecting information from monitoring and sensing devices.

Digital Twin system entity uses the collected information to synchronize the Digital Twin with its corresponding observable manufacturing element.

Data collection sub-entity may include executables in the form of a program or an agent.

5.2.3.3 Device control sub-entity

Device control sub-entity interacts with the observable manufacturing element by controlling and actuating devices such as CNC controls. Device control sub-entity may include executables in the form of a program or an agent.

5.2.4 Digital Twin system entity

5.2.4.1 Operation and management sub-system entity

Operation and management sub-system entity operates and manages Digital Twin. Operation and management sub-system entity shall maintain information of observable manufacturing element both in production and in design, including digital modeling, presentation, and synchronization. In addition, operation and management sub-system entity supports capabilities related to operation and management of overall Digital Twin system entity such as providing administration functionality to Digital Twin user entity.

5.2.4.2 Application and service sub-system entity

Digital Twin system entity provides various kinds of applications and services including simulation of manufacturing system, analysis of data captured from observable manufacturing element, reporting of actions such as production, etc. Application and service sub-system entity provides functionalities related to applications and services.

5.2.4.3 Resource access and interchange sub-system entity

Resource access and interchange sub-system entity provides access to functionalities of Digital Twin system entity to Digital Twin user entity with controlled interfaces for application and service functionalities, administration functionalities, and business functionalities in support of interoperability. Access and interchange control functions may vary depending on the type of Digital Twin user entity requiring authentication, authorization and other necessary actions.

5.2.5 Digital Twin user entity

As shown in Figure 3, Digital Twin user entity can be any entity that can utilize Digital Twin for manufacturing such as a person, a device, manufacturing execution system (MES)/enterprise resource planning (ERP) systems, or even peer Digital Twin system entity. Appropriate interface shall be offered to Digital Twin user entity, where application specific capabilities are supplied by an underlying application that interacts with Digital Twin system entity by means of APIs controlled by Resource access and interchange sub-system entity.

5.2.6 Cross-system entity

Cross-system entity is an entity that resides across domains to provide common functionalities such as information exchange, data assurance, security support, etc.

5.3 Domain-entity mixed reference model

Figure 4 shows a domain-entity mixed reference model. This is a reference model, therefore both domains and entities can be extended, merged, or added depending on practical use cases.

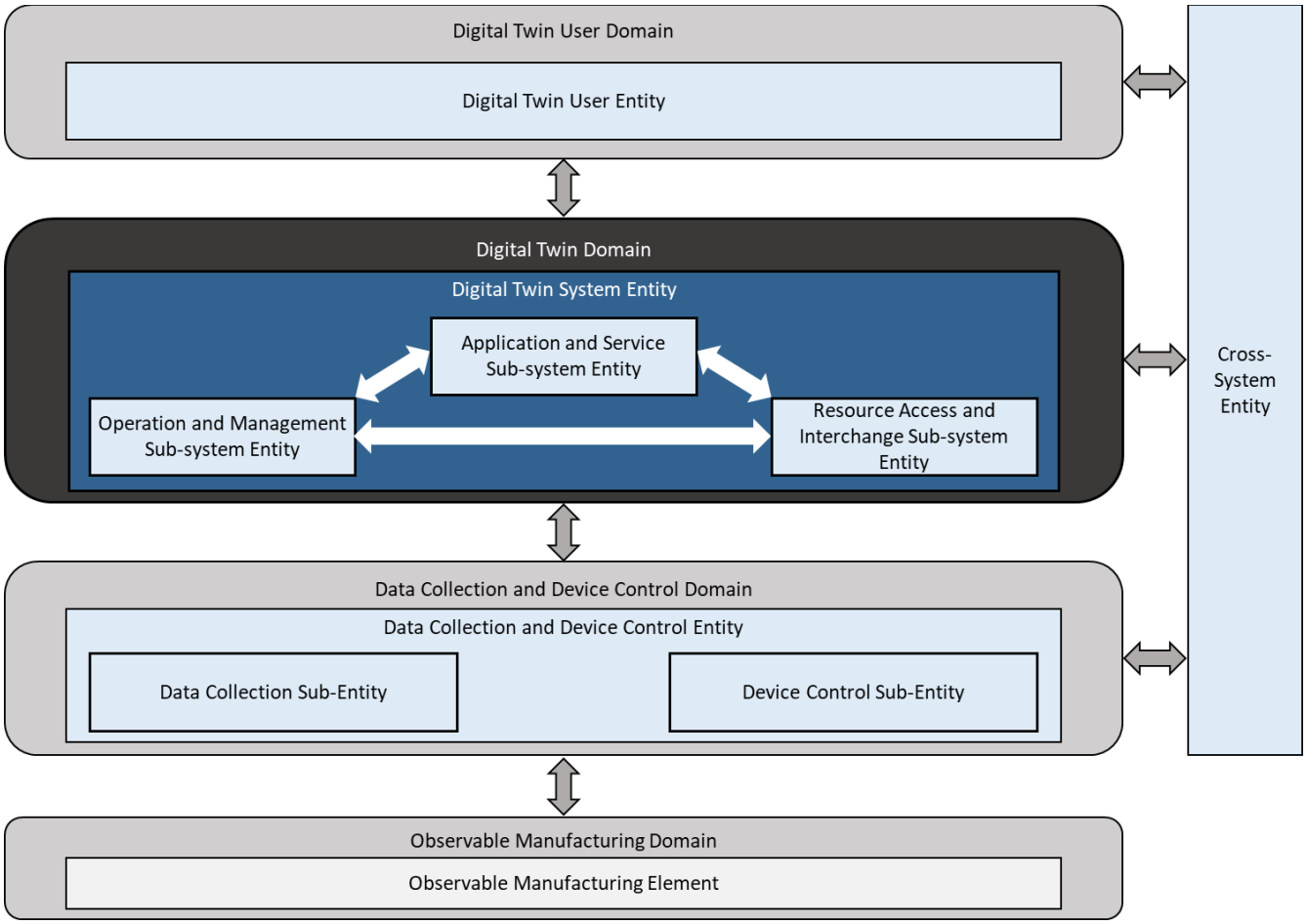

Figure 4 – Domain-entity mixed Digital Twin reference model for manufacturing

6 Digital Twin reference architectural views for manufacturing

6.1 General

This clause defines functional view and networking view of Digital Twin reference architecture for manufacturing.

6.2 Functional view

6.2.1 Functional reference architecture

Digital Twin reference architecture for manufacturing provides an infrastructure to support a large number of Digital Twins. Figure 5 shows a functional reference architecture to support requirements defined in ISO 23247-1.

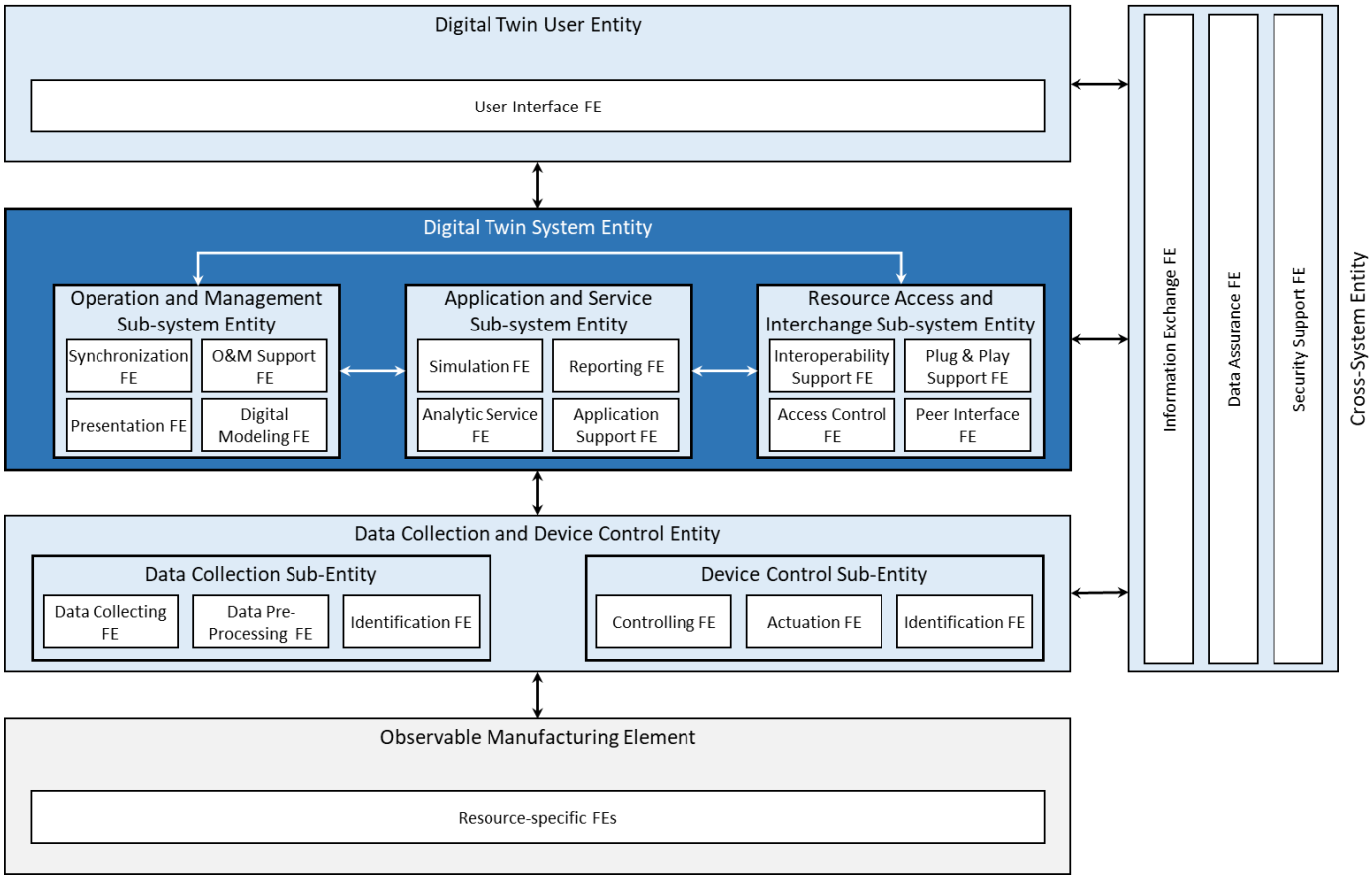

Figure 5 – Functional reference architecture of Digital Twin for manufacturing – decomposition of functional entities (FEs)

6.2.2 Functional entity of observable manufacturing element

Resource-specific FE is a functional entity of an observable manufacturing element. It shall be digitally modelled to be utilized by entities in Digital Twin for manufacturing.

6.2.3 Functional entity of data collection and device control entity

6.2.3.1 Data collecting FE in data collection sub-entity

Data collecting FE provides data collection functionality from observable manufacturing element.

6.2.3.2 Data pre-processing FE in data collection sub-entity

Data pre-processing FE provides pre-processing functionality for collected data, for example filtering and aggregation.

6.2.3.3 Controlling FE in device control sub-entity

Controlling FE provides functionality of controlling observable manufacturing element by the request from Digital Twin system entity.

6.2.3.4 Actuation FE in device control sub-entity

Actuation FE provides functionality of actuating observable manufacturing element by the request from Digital Twin system entity, similarly with controlling FE.

6.2.3.5 Identification FE in data collection sub-entity and device control sub-entity

Identification FE provides functionality of identifying observable manufacturing element and its data to be collected and controlled uniquely and unambiguously.

6.2.4 Functional entity in Digital Twin system entity

6.2.4.1 Functional entity in operation and management sub-system entity

6.2.4.1.1 Synchronization FE

Synchronization FE provides functionality of synchronizing the status of the visualized digital entity with the status of the observable manufacturing element, or vice versa.

6.2.4.1.2 Presentation FE

Presentation FE provides functionality of presenting observable manufacturing element as digital entity in conjunction with digital modeling FE.

6.2.4.1.3 Digital modeling FE

Digital modeling FE provides functionality of interpreting information of observable manufacturing element to understand its physical properties, status, etc.

6.2.4.1.4 O&M support FE

O&M support FE provides functionalities of operating and managing Digital Twin and Digital Twin system entities.

6.2.4.2 Functional entity in application and service sub-system entity

6.2.4.2.1 Simulation FE

Simulation FE provides functionalities of simulation.

6.2.4.2.2 Analytic service FE

Analytic service FE provides functionality of analysing data collected from observable manufacturing element and the result of simulation.

6.2.4.2.3 Reporting FE

Reporting FE provides functionality of generating report of production result, analysis on simulation, etc.

6.2.4.2.4 Application support FE

Application support FE provides functionality of hosting platform for implementing predictive and reactive, open and closed loop applications.

6.2.4.3 Functional entity in resource access and interchange sub-system entity

6.2.4.3.1 Interoperability support FE

Interoperability support FE provides functionality of interworking with other Digital Twin system entity in conjunction with peer interface FE.

6.2.4.3.2 Access control FE

Access control FE provides functionality of controlling access of Digital Twin user entity to observable manufacturing element in conjunction with security support FE.

6.2.4.3.3 Plug & play support FE

Plug & play support FE provides functionality of dynamic involvement of observable manufacturing element, i.e., joining and leaving Digital Twin for manufacturing in run time, in conjunction with O&M support FE.

6.2.4.3.4 Peer interface FE

Peer interface FE provides functionality of interfacing to other Digital Twin entities in conjunction with interoperability support FE.

6.2.5 Functional entity in Digital Twin user entity

6.2.5.1 User interface FE

User interface FE provides Digital Twin user entity with functionality of interfacing to Digital Twin system entity.

6.2.6 Functional entity in cross-system entity

6.2.6.1 Information exchange FE

Information exchange FE provides functionality of exchanging information among entities of Digital Twin for manufacturing by appropriate networking protocols.

6.2.6.2 Data assurance FE

Data assurance FE provides accuracy and integrity of data in conjunction with security support FE.

6.2.6.3 Security support FE

Security support FE provides functionality of securing Digital Twin for manufacturing including authentication, authorization, confidentiality, integrity, etc.

6.3 Networking view

6.3.1 Networking reference architecture

Networking reference architecture describes communication network which are involved in Digital Twin for manufacturing.

Figure 6 shows three principal communication networks in terms of domain-entity mixture reference model (see 5.3) in Digital Twin for manufacturing. Main role of communication network provides means to exchange information between entities across the different domains.

However, data collection and device control entity is physically attached or integrated into observable manufacturing element, therefore communication network between these two entities is not considered in this document.

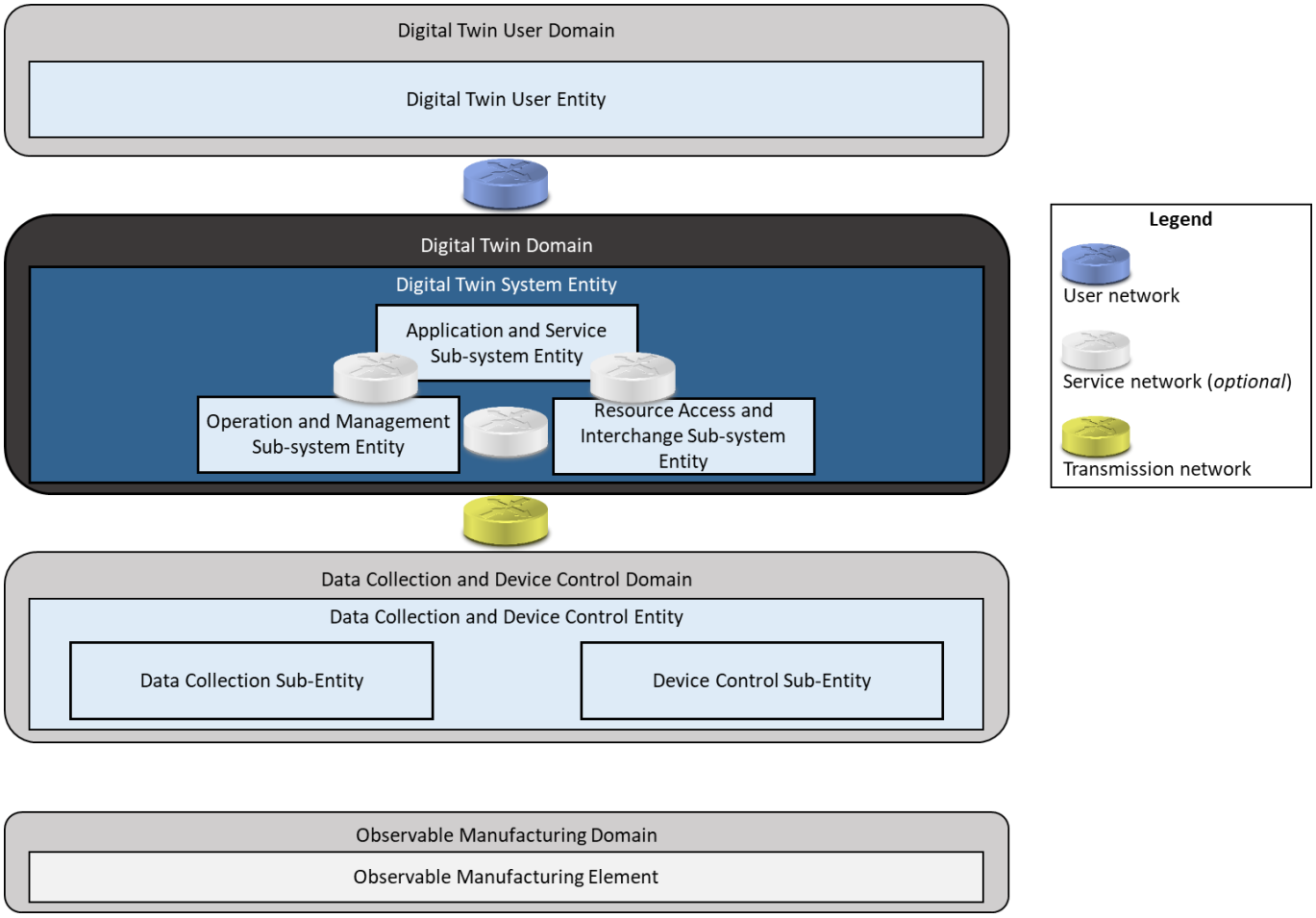

Figure 6 – Networking view of Digital Twin reference architecture for manufacturing

6.3.2 Transmission network

Transmission network connects data collection and device control entity to Digital Twin system entity, i.e., operation and management sub-system entity, application and service sub-system entity, and resource access and interchange sub-system entity. Through this network, data collection sub-entity transmits collected data from observable manufacturing element to the target entities of Digital Twin system entity. In addition, control information for observable manufacturing element is delivered to device control sub-entity from entities of Digital Twin system entity.

Typical examples of transmission network can be wired communication such as LAN, and wireless communication such as WLAN and mobile (cellular) network, which generally adopt IP-based communication protocols regardless of communication type.

Information exchange between data collection and device control entity, and Digital Twin system entity over transmission network is supported by appropriate communication protocol. For example, MTConnect and OPC-UA can be used as information exchange protocol. ISO 23247-4 defines information exchange over transmission network. However, if data collection and device control entity, and Digital Twin system entity are implemented in one system, it might not be necessary to have transmission network.

6.3.3 Service network (optional)

Service network connects operation and management sub-system entity, application and service sub-system entity, and resource access and interchange sub-system entity with each other, which are typically wired networks running IP-based protocols.

Service network can include both typical Internet and also (private) Intranet in case that Digital Twin system entity is implemented in a single private domain, even a single system. In this case, a service network is not needed and dedicated connections can be applied to a single private domain connecting different entities as well as internal communication within a single system. ISO 23247-4 defines information exchange over service network.

6.3.4 User network

User network connects Digital Twin user entity with Digital Twin system entity. In case that Digital Twin user entity is one of MES, ERP, other manufacturing management system, and even other Digital Twin system entity, this type of Digital Twin user entity is connected to resource access and interchange sub-system entity over user network.

User network is typically based on Internet and uses IP. Such networks can use any of the technologies commonly used to exchange information. ISO 23247-4 defines information exchange over user network.

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