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Automation systems and integration – Digital Twin framework for manufacturing– Part 4: Information exchange

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DIS stage

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Foreword

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This document was prepared by Technical Committee ISO/TC 184, *Industrial 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.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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 the Digital Twin framework for manufacturing;

- Part 2: Reference architecture

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

- Part 3: Digital representation of manufacturing elements

  Identifies the observable 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 between entities of the reference model of 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 the Digital Twin framework for manufacturing will be detailed in technical reports attached to this series of standards.

Automation systems and integration – Digital Twin framework for manufacturing– Part 4: Information exchange

1 Scope

This part of ISO 23247 identifies technical requirements for information synchronization and information exchange between entities of the reference model of the Digital Twin framework 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, and products.

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

- scope statement for ISO 23247 as a whole;
- overview of ISO 23247-4;
- requirements for information exchange A;
- requirements for information exchange B;
- requirements for information exchange C;
- requirements for information exchange D.

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);
- digital representation of manufacturing elements of the Digital Twin framework for manufacturing (Part 3);
- use cases of the Digital Twin framework for manufacturing 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 manufacturing framework — Part 1: Overview and general principles*

ISO 23247-2, *Automation systems and integration — Digital Twin manufacturing framework — Part 2: Reference architecture*

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/

4 Overview

[Editorial note] Digital Twin entity will be updated to new name before DIS ballot. (All text, Figure 1~4, Figure A.1~A.4)

ISO 23247-2 defines a functional view of Digital Twin reference model for manufacturing. Each entities and observable manufacturing elements in the reference model are peers of information exchange. This document specifies four types of information exchange between entities and observable manufacturing element as shown in Figure 1. In addition, this document defines requirements for each type of information exchange that the functional entities should provide.

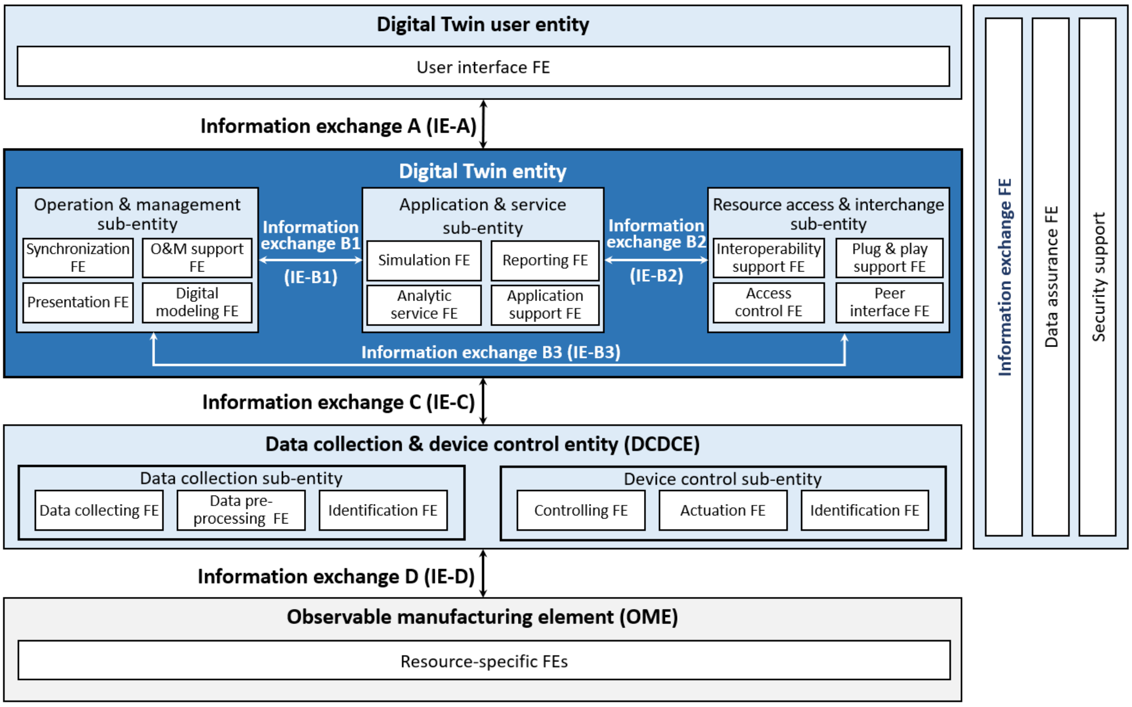


Figure 1 — Reference Architecture of Digital Twin Framework for Manufacturing

The four types of information exchange are as follows:

– The information exchange A (IE-A) is an interface between Digital Twin user entity and Digital Twin entity;

– The information exchange B1 (IE-B1), information exchange B2 (IE-B2), and information exchange B3 (IE-B3) are the interfaces among three sub-entities within the Digital Twin entity;

NOTE The three sub-entities are Operation & management sub-entity, Application & service sub-entity, and Resource access & interchange sub-entity.

– The information exchange C (IE-C) is an interface between the Digital Twin entity and Data collection and device control entity (DCDCE);

– The information exchange D (IE-D) is an interface between DCDCE and Observable manufacturing element (OME).

5 Requirements for information exchange A (IE-A)

[Editorial Notes] examine for the need to change some requirements to "shall"(JP06-013). This note to be removed before DIS ballot.

5.1 Overview

The IE-A is an interface between Digital Twin User Entity and Digital Twin Entity, in which Digital Twin User Entity uses services and applications provided by Digital Twin Entity as shown in Figure 2.

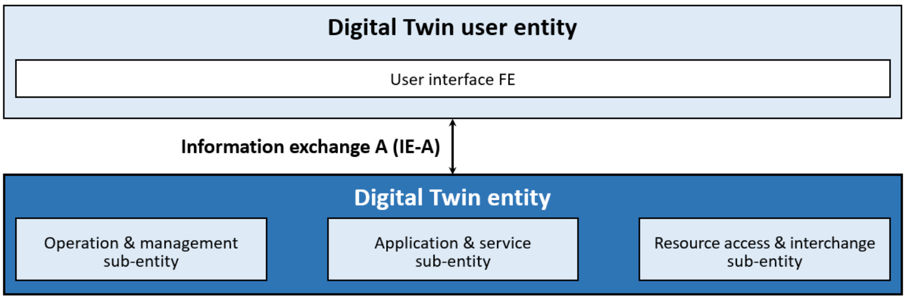


Figure 2 — Position of information exchange A (IE-A)

5.2 Visualization

IE-A should support visualization…

[Editorial Notes] Add requirements for visualization.

5.3 Standardized method for data exchange

[Editorial Notes] check for more requirements, if needed (CN-028). This note to be removed before DIS ballot.

IE-A should provide standardized method in exchanging data (e.g., use of standardized protocol) for the Digital Twin user entity to use services from the Digital Twin.

NOTE Some examples for standardized method are described in Annex A.2.1.

5.4 Transaction method

IE-A may use any of the three types of transaction method that follows:

– PULL method: user requests information from the information provider;

NOTE 1 In IE-A, Digital Twin user entity is the user, and Digital Twin entity is the information provider in the PULL method.

– PUSH method: sender sends new or changed information to the receiver;

NOTE 2 In IE-A, Digital Twin user entity is the receiver, and Digital Twin entity is the sender in the PUSH method.

– PUBLISH method: publisher publishes data to be received by the subscribers.

NOTE 3 In IE-A, Digital Twin user entity is the subscriber, and Digital Twin entity is the publisher in the PUBLISH method.

If Digital Twin user entity consists of one or two dedicated (or exclusive, private) applications, it is possible to use PULL or PUSH method. If Digital Twin user entity consists of multiple arbitrary applications, it is recommended to use PUBLISH method.

PUSH method can be used for transferring emergency information that requires immediate action by the receiver. Emergency information includes reports from errors, faults, and warnings. PUSH method can also be used to transfer message for predictive maintenance.

5.5 Security

IE-A should provide secure method of communication in terms of authentication, authorization, data integrity, privacy, confidentiality, etc.

IE-A needs to confirm that correct information is received and delivered to the correct application without being disclosed to unauthorized third party.

6 Requirements for information exchange Bs (IE-B1, IE-B2, IE-B3)

6.1 Overview

The IE-Bs are interfaces among three sub-entities (i.e., Operation & management sub-entity, Application & service sub-entity, and Resource access & interchange sub-entity) within Digital Twin entity. Through IE-Bs, sub-entities exchange information for the Digital Twin entity to provide Digital Twin services for manufacturing as shown in Figure 3.

NOTE ISO 23247-2 describes functionalities of the three sub-entities as follows:

- Operation & management sub-entity operates and manages Digital Twin entity by maintaining information of the observable manufacturing element;
- Application & service sub-entity provides functionalities related to simulation of manufacturing system, analysis of data captured from observable manufacturing element, reporting of action such as production, etc;
- Resource access & interchange sub-entity provides access to functionalities to Digital Twin user entity with controlled interfaces for application and service functionalities, administration functionalities, and business functionalities in support of interoperability.

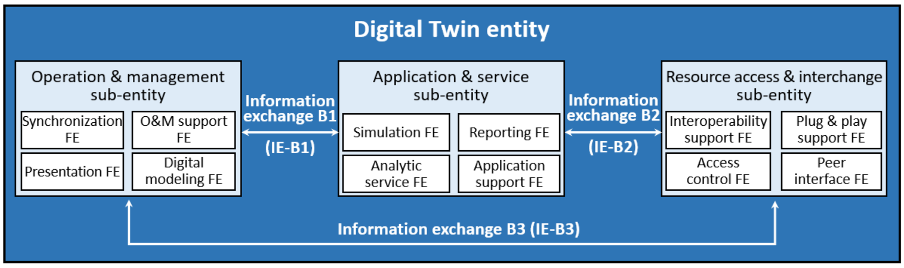


Figure 3 — Position of information exchange Bs (IE-B1, IE-B2, IE-B3)

The IE-Bs consists of IE-B1, which is an interface between Operation & management sub-entity and Application & service sub-entity, of IE-B2, which is an interface between Application & service sub-entity and Resource access & interchange sub-entity, and of IE-B3, which is an interface between Operation & management sub-entity and Resource access & interchange sub-entity.

6.2 Digital Twin services

IE-Bs shall exchange information to provide services for recreating history, services for monitoring the present status for various viewpoints, and services for simulation in order to plan for the future.

NOTE Digital Twin entity collects data from observable manufacturing elements through IE-C. Digital Twin entity may use artificial intelligence to analyse the collected data. Based on data analytics, Digital Twin entity can reproduce the past, diagnose the present, and plan for the future.

6.3 Presentation

IE-Bs should support presentation…

[Editorial Notes] Add requirements for presentation.

[Editorial Notes] Add requirements regarding QIF (measurement?).

6.4 Digital model

The Digital Twin of observable manufacturing elements are generated from digital model through synchronization with observable manufacturing elements. IE-C shall have capability to exchange information for presentation of digital model corresponding to the observable manufacturing elements.

NOTE Information for presentation includes visualization, static and dynamic information, change history, etc.

6.5 Implementation dependent

IE-Bs are implementation dependent and it is out of the scope of this document.

NOTE The three sub-entities within Digital Twin entity can be implemented in a single system/device or among multiple system/devices. The process or processor that operates within the Digital Twin entity can use function calls, IPC, shared memory or any techniques. Thus, information exchanged in IE-Bs are implementation dependent, and it is out of the scope of this document.

7 Requirements for information exchange C (IE-C)

7.1 Overview

The IE-C is an interface between Digital Twin entity and DCDCE, in which the Digital Twin entity collects information from observable manufacturing elements and controls devices in observable manufacturing elements as shown in Figure 4. The Digital Twin entity maintains Digital Twin of observable manufacturing element which is defined in ISO 23247-3.

NOTE 1 DCDCE interacts with OME(s). DCDCE monitors, senses, and in some cases, DCDCE performs actuation on OME(s) or controls OME(s). Digital Twin entity uses DCDCE as a mediator to retrieve information of the OME(s) or to control OME(s).

NOTE 2 Annex A.4 shows some examples on how the Digital Twin entity and DCDCE are configured using various protocols for collecting and controlling data.

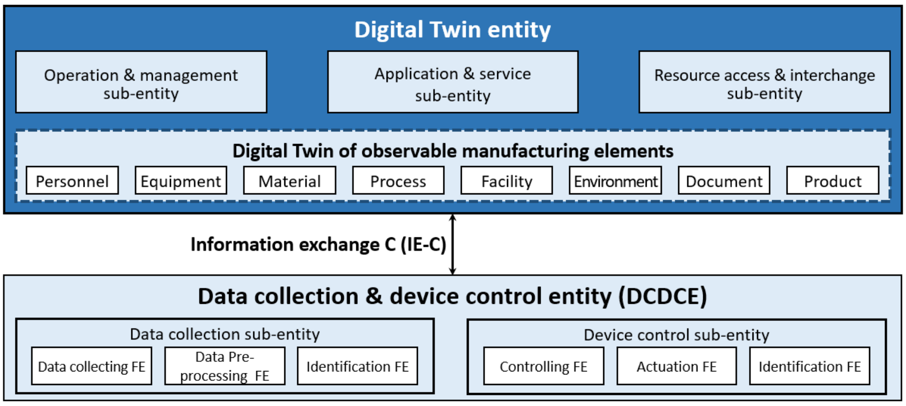


Figure 4 — Position of information exchange C (IE-C)

7.2 Connectivity

IE-C shall provide networking capability to allow Digital Twin entity and the DCDCE to connect to the network.

IE-C shall provide methods for the Digital Twin entity and the DCDCE to discover, identify, and create relationships with each other.

NOTE Multiple devices (including sensors, manufacturing elements) will be participating in the Digital Twin services. The devices can be connected and disconnected any time during the Digital Twin services. Since a device are controlled by the DCDCE, Digital Twin entity will need to handle the join/leave activities of the multiple DCDCEs with plug-and-play support.

7.3 Standardized method for data exchange

[Editorial Notes] check for more requirements, if needed (CN-039). This note to be removed before DIS ballot.

IE-C should provide a standardized method for exchanging data (e.g., use of standardized protocol).

NOTE Digital Twin entity acts as an application with DCDCE providing source data of the OME(s) through the use of standardized protocol. The information exchanged in IE-C are characteristics, capabilities, status, location, etc. The ISO 23247-3 defines the contents for this requirement.

7.4 Identification

IE-C should be able to identify observable manufacturing elements and set unique identification (or name).

NOTE There can be Digital Twin for multiple observable manufacturing elements in the Digital Twin entity. There should be an identification scheme to map the observable manufacturing elements with the corresponding Digital Twin. In some cases, the sensors or the actuators are not represented by the Digital Twin, however, they need to provide sensing data or actuation results to the Digital Twin entity. For this reason, Digital Twin entity will need to identify the sensors and the actuators of observable manufacturing elements.

7.5

7.6 Applying manufacturing information

IE-C should have the capability to interface with manufacturing applications to apply manufacturing information to Digital Twins.

NOTE DCDCE can be a manufacturing application such as MES, ERP, O&M system, or another Digital Twin systems for manufacturing. Manufacturing information includes product planning, manufacturing execution, production results, quality test results.

7.7 Synchronization

[Editorial Notes] check for more requirements on certainty during synchronization(best-effort? Guaranteed communication?), if needed (CN-045). This note to be removed before DIS ballot.

IE-C shall have capability to exchange data for synchronization of changes among multiple Digital Twins.

NOTE Multiple devices such as production line can consist of multiple Digital Twins. A change in Digital Twin of a single device can have effect on the other related Digital Twin.

IE-C shall have capability to exchange data for synchronization of changes from observable manufacturing elements to Digital Twin.

IE-C may have capability to exchange data for synchronization of changes from Digital Twin to observable manufacturing elements.

Network bandwidth in IE-C should be sufficient to support required level of synchronization.

NOTE Massive data from devices and sensors are exchanged in IE-C as with the increase of detailed level synchronization of observable manufacturing elements with Digital Twin. Application needs to check if sufficient network bandwidth is available in IE-C to support such level of synchronization.

7.8 Operation on Information exchange

IE-C shall provide a method for the Digital Twin entity to receive the data of the observable manufacturing elements.

IE-C may provide a method for the Digital Twin entity to update/change the data of the observable manufacturing elements.

IE-C may provide a method for the Digital Twin entity to control the observable manufacturing elements.

IE-C should provide a method for the Digital Twin entity to create necessary Digital Twins for new observable manufacturing elements.

IE-C should provide a method for the Digital Twin entity to delete corresponding Digital Twins as with the removal or disconnection of the observable manufacturing elements. IE-C should provide method for the DCDCE to send periodic data to trace changes of the observable manufacturing elements.

NOTE 1 Digital Twin entity needs to retrieve periodic data from DCDCE in order to apply any changes to the Digital Twin. The periodic data may be stored to be used in Digital Twin services such as replicating the past, big data analysis.

IE-C should provide a method for the DCDCE to stop sending periodic information.

IE-C should provide a method for the DCDCE to notify when certain condition occurs.

NOTE 2 Dynamic data such as status changes are typical candidates for notification.

7.9 Transaction method

IE-C may use any of the three types of transaction methods (PULL method, PUSH method, PUBLISH method).

PUBLISH method is recommended, if there are multiple Digital Twin systems for manufacturing and multiple manufacturing applications that are receiving data from DCDCE.

NOTE The descriptions of the three types of transaction method are in clause 5.3.

7.10 Support of near real-time communication

IE-C may support near real-time communication, if the Digital Twin needs to receive near real-time information.

NOTE The necessity of near real-time communication is application dependent. Urgent fault or alarm that needs immediate attention is one reason to use near real-time communication.

[Editorial Notes] check for more requirements, if needed (CN-051). This note to be removed before DIS ballot.

7.11 Support of twinning of mobile devices

IE-C may support mobility, if the Digital Twin needs to show the location of the mobile devices which is one of the observable manufacturing elements.

[Editorial note] consider adding requirement(s) for network bandwidth (clause 7.6) and mobility (CN-015, CN-016). This note to be removed before DIS ballot.

7.12 Security

IE-C may consider security issues as follows:

– Authentication and authorization:

  Authentication is a process of establishing the identity of the user or processer. Authorization is permitting access right or privileges to the resources. Authentication and authorization are an issue when multiple observable manufacturing elements are involved in Digital Twin. There are high chances of showing incorrect information when Digital Twin interacts with unauthorized physical devices;

– Data integrity:

Data integrity is completeness, accuracy and consistency of data. Many observable manufacturing elements and IoT devices are involved to create an accurate Digital Twin, which leads to massive data flooding to the Digital Twin. It is critical for the DCDCE to check data integrity, filtering unnecessary and inaccurate data;

– Privacy and confidentiality:

Privacy is an ability to secure individual or group information from public attention. Confidentiality is protection of sensitive and private data from being disclosed to the public. Digital Twin involves twinning of the observable manufacturing elements including personnel, equipment, material, process, facility, and products. Data generated from the observable manufacturing elements and various IoT devices is private and sensitive data for the manufacturer that needs to be protected. It is possible for the Digital Twin to provide methods such as data encryption to ensure that data are not disclosed to the public

8 Requirements for information exchange D (IE-D)

8.1 Overview

The IE-D is an interface between DCDCE and OME. The IE-D may not be necessary, if the OME supports direct interface with Digital Twin entity by physically attached or integrated DCDCE to the OME.

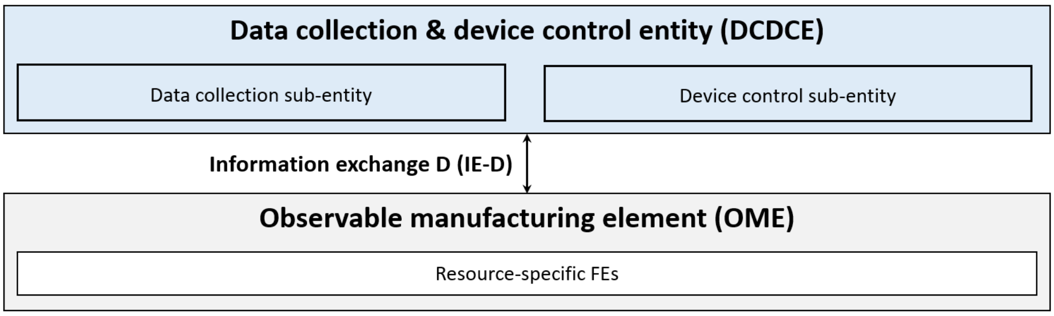


Figure 5 — Position of information exchange D (IE-D)

8.2 Support of local network

IE-D should be connected with the DCDCE through the local network.

NOTE 1 The local network in this document refers to Industrial Ethernet or a proprietary network. Many manufacturing equipment have connectivity with an Industrial Ethernet or proprietary network. Industrial Ethernet is an Ethernet that is used in an industrial environment in limited configurations. Industrial Ethernet provides determinism and real-time control.

NOTE 2 Many factories establish a local network (or closed network) in the shop floor to protect internal data from being revealed and being modified by the outside world. The DCDCE can be a part of a gateway of the local network and collect and filter data for Digital Twin support.

8.3 Support of adaptation

IE-D should support adaptation of data received from OME to data that is understood by DCDCE.

IE-D should support adaptation of data received from DCDCE to data that is understood by OME.

NOTE Normally, DCDCE have an interface to the global IP network, i.e. external network. DCDCE needs to translate data from local network to data that is understood by the external network. The DCDCE will need to filter unnecessary data and perform pre-processing before delivering it to the external network. DCDCE also needs to translate data from the external network before delivering it to the local network.

Annex A
(informative)

Technical discussion -
Implementation options for Digital Twin framework for manufacturing

A.1 Acronyms of protocols

This clause lists acronyms of protocols or standards that can be considered as an implementation options of Digital Twin framework for manufacturing.

AES	Advanced Encryption Standard
AMF	Additive Manufacturing File format
API	Application Program Interface
AutomationML	Automation Markup Language
B2MML	Business To Manufacturing Markup Language
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
CBC	Cipher-Block Chaining
CCM	Counter with CBC-MAC
CDD	Common Data Dictionary
CFX	Connected Factory Exchange
ECDHE	Elliptic-curve Diffie–Hellman
EtherCAT	Ethernet for Control Automation Technology
HTTP	HyperText Transfer Protocol
IPC	Inter-Process Communication
ISA	International Society of Automation
JSON	JavaScript Object Notation
JT	Jupiter Tesslation
LwM2M	Lightweight Machine to Machine
MOM	Manufacturing Operations Management
MQTT	Message Queuing Telemetry Transport
MTConnect	Machine Tool Connect
OCF	Open Connectivity Foundation
OID	Object IDentifier
OPC-UA	Open Platform Communications - Unified Architecture
OpenGL	Open Graphics Library
OTD	Open Technical Dictionary
PLC	Programmable Logic Controller
PSK	Phase-Shift Keying
QIF	Quality Information Framework
RAMI 4.0	Reference Architectural Model Industrie 4.0
RAPINet	Real-time Automation Protocols for Industrial Ethernet

REST	REpresentational State Transfer
RSA	Rivest–Shamir–Adleman
SHA	Secure Hash Algorithm
STEP	Standard for the Exchange of Product model data
TSN	Time-Sensitive Networking
UUID	Universal Unique Identifier
URI	Uniform Resource Identifier
WebGL	Web Graphics Library
XML	eXtensible Markup Language

A.2 Implementation options for four IEs

Figure A.1 describes an implementation options for four IEs using various existing protocols.

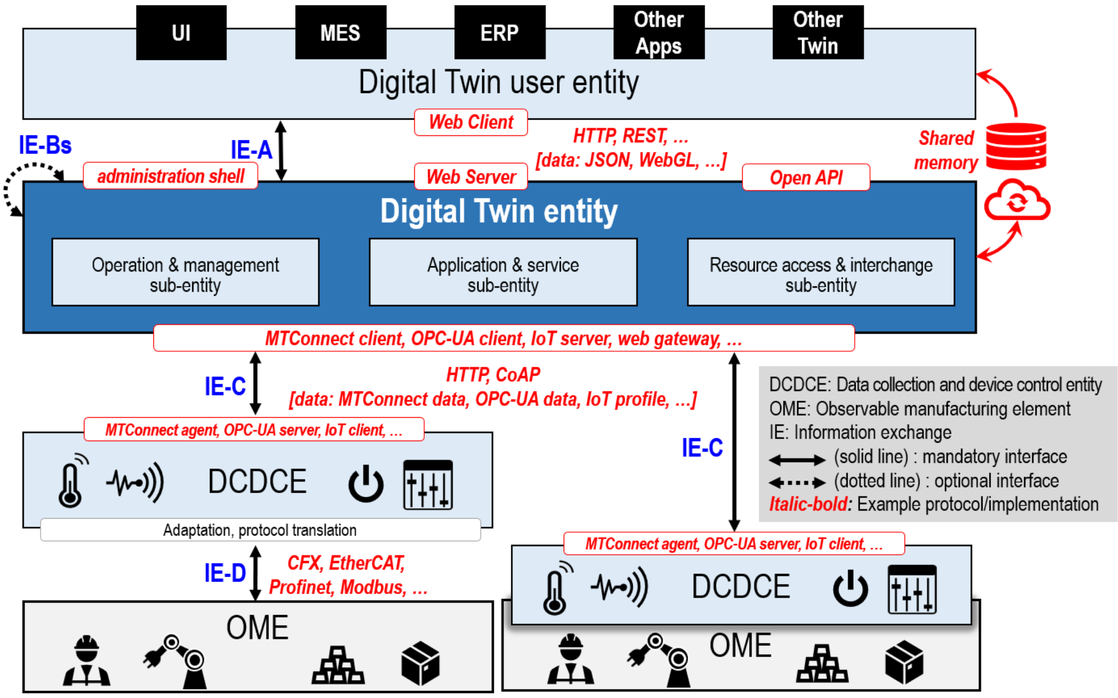


Figure A.1 — Implementation options for four IEs

A.2.1 Implementation options for IE-A

The implementation options for IE-A are as follows:

- Regarding standardized methods for data exchange, Digital Twin entity can provide web services for the Digital Twin user entity (with web client application) to use services provided by Digital Twin entity through a web interface using HTTP or REST within IE-A. HTTP is a set of rules for transferring files (e.g., text, image, multimedia data) through the web. REST is an architectural style defining set of constraints to be used in web application. The data format that can be used includes JSON, XML, etc. JSON is a lightweight data-interchange format for storing and transporting data. It is a human-readable text consisting of attribute-value pairs and array data types. XML is a text-based format used to share data. To exchange graphical information, it is possible to use API such as WebGL, OpenGL. WebGL is a JavaScript API for rendering 2D/3D graphics. OpenGL is an API for rendering 2D/3D graphics;
- Digital Twin entity can define open APIs to access services from Digital Twin. Digital Twin user entity can use the open APIs in its applications. Open API (i.e., public API) is an application programming interface that is available to the public. It allows user software (i.e., Digital Twin user entity) to access internal functions of the program (i.e., Digital Twin entity). Web interface is one example of Open API;
- Digital Twin entity and Digital Twin user entity can use shared memory (e.g. database, cloud) to store the information generated by the Digital Twin entity. Digital Twin user entity can search and fetch the needed information. A schema needs to be defined for accessing information provided by the Digital Twin services.

– To support visualization, it is possible to use ISO 14306 (i.e., JT) which defines the syntax and semantics of a file format for the 3D visualization and interrogation of lightweight geometry and product manufacturing information derived from CAD systems, using visualization software tools that do not need the full capability of a CAD system. … *To provide web-based graphical information,* it is possible to use API such as WebGL, OpenGL. WebGL is a JavaScript API for rendering 2D/3D graphics. OpenGL is an API for rendering 2D/3D graphics.

– *[Editorial note] rewriting needed to specify implementation option for* visualization*:* IEC 62714 is an XML based data format for exchanging plant engineering information. Some application uses a factory layout (blueprint) to create initial digital model of the shop floor.

[Editorial note] consider adding implementation options for JT, 3DPDF, 3D Rendering (visualization perspective);

- JT (ISO 14306:2017, Industrial automation systems and integration — JT file format specification for 3D visualization(visualization)

- 3DPDF: 3D PDF is a PDF file with 3D geometry inside. Using any 3D PDF enabled viewer, rotation, zoom and part selection is available within the 3D view. This is often used for documentation, sharing and collaboration. (visualization)

- 3D Rendering: 3D computer graphics process of converting 3D models into 2D images on a computer. 3D renders may include photorealistic effects or non-photorealistic styles. (visualization)

[Editorial note] consider adding implementation option for administration shell (AAS) in IE-A. (Note, The asset administration shell (AAS) provides serializations in JSON, XML and (in work) RDF. (in Work): REST-API - So AAS is an example how to implement IE-A)

A.2.2 Implementation options for IE-Bs

The implementation options for IE-Bs are as follows:

– For information exchange in IE-Bs, it is possible to use the same type of protocols, APIs, and descriptive language as in IE-A;

– To support presentation, …

– *[Editorial note] rewriting needed to specify implementation option for presentation:* CAD/CAM information can be used to create the digital model of the observable manufacturing element(s). There are various standards that can be used for digital modelling such as ISO 10303-242 (i.e., STEP AP242), ISO 10303-238 (i.e., STEP AP238), ISO 10303-239 (i.e., STEP AP239), IEC 62714 (i.e., AutomationML). ISO 10303-242 supports managed model-based 3D engineering. ISO 10303-238 supports control language for controlling machine tools. ISO 10303-239 supports product lifecycle. Some application uses a factory layout (blueprint) to create initial digital model of the shop floor.

[Editorial note] consider adding implementation options for JT, 3DPDF, 3D Rendering (presentation perspective);

From https://all3dp.com/3d-file-format-3d-files-3d-printer-3d-cad-vrml-stl-obj/

We simply explain the most common 3D file formats used today: STL, OBJ, FBX, COLLADA, 3DS, IGES; STEP, and VRML/X3D.

A 3D file format is used for storing information about 3D models. You may have heard of the most popular formats STL, OBJ, FBX, COLLADA etc. They are widely used in 3D printing, video games, movies, architecture, academia, medicine, engineering, and earth sciences.

– To support *xxx*, it is possible to use standard such as ISO 23952 (i.e., QIF). ISO 23952 is an XML based standard which defines, organizes, and associates quality information. With QIF, the Digital Twin can be adjusted to be synchronized with the measured value. With big data analysis of the QIF measured value, the accuracy of the predictive results can be increased.

– To provide Digital Twin services, data are gathered and stored from various data sources. Data can be stored in a time table or event driven.

A.2.3 Implementation options for IE-C

The implementation options for IE-C are as follows:

– For connectivity between Digital Twin entity and DCDCE, Digital Twin entity can broadcast to the network of its existence, method on connectivity, etc. DCDCE can use that information to connect to the Digital Twin entity. DCDCE can be preconfigured to support plug-and-play with the Digital Twin entity;

– Regarding standardized method for data exchange, Digital Twin entity can access/manipulate OME using protocols such as MTConnect, OPC-UA, RAMI 4.0 administration shell. Digital Twin entity acts as an application with DCDCE providing source data of the OME(s) through the standardized protocol;

– Digital Twin entity can access/manipulate IoT devices (e.g., sensors, actuators) using protocols such as OPC-UA, OCF, LwM2M, oneM2M, etc. IoT protocols have defined various data format that are exchanged in the protocols. It is possible to define new data format for customized purposes;

– Digital Twin entity can access applications such as MES, ERP. Digital Twin entity can get manufacturing-related data or modeling-related data through interface with the application. DCDCE needs to support interface with such applications;

– Regarding Identification, there are many standards such as ISO 22745, IEC 61360, IEC 61987, ITU-T X.660 | ISO/IEC 9834-1, ITU-T X.667 | ISO/IEC 9834-8, IETF STD 66 that can be used as a reference for identification scheme of OME. ISO 22745 (i.e., OTD) defines database of concepts with associated terms, definitions and images used for description of individuals, organizations, locations, goods, services, processes, rules and regulations. IEC 61360 (i.e., CDD) defines data model to be used for providing classifications and metadata definitions for describing products. The CDD for process automation equipment are defined in IEC 61987. ITU-T X.660 | ISO/IEC 9834-1 (i.e., OID) defines identification mechanism for naming any type of object, concept or 'thing' with globally unique name. ITU-T X.667 | ISO/IEC 9834-8 (i.e., UUID) defines identification mechanism using 128-bit number generated by algorithm with values that are based on a machine's network address to uniquely identify object or entity on the Internet. IETF STD 66 (i.e., URI) is defines identification mechanism with string of characters used to unambiguously indentify a logical or physical resources on the network, of which the best known type is web address (e.g. http://);

– Regarding digital model, if it is possible to identify the manufacturer and model number of OME from the identification, it is possible to develop an initial digital model of the OME with the pre-stored information such as visualization, capabilities provided, parameter, or standard used;

– To apply manufacturing information, the standards to consider are in IEC 62264 series (i.e., ISA-95) which define the automated interface between enterprise and control systems. B2MML is an XML implementation of IEC 62264. B2MML can be used to extract information on manufacturing (e.g., asset tracking, inventory management) that can be applied to the Digital Twin for simulation or analytic services. The ISO 16100 series can also be considered, since it defines manufacturing information model that characterizes software-interfacing requirements enabling the interoperability among manufacturing software tools (modules or systems). The ISO 18828 series defines seamless production planning. It can be used as a reference for exchanging information regarding changes of production planning;

- To support synchronization of changes, it is possible to use standardized data format such as ISO/ASTM 52915(i.e., AMF). ISO/ASTM 52915 is an XML based format for describing objects for additive manufacturing process such as 3D printing;
- To support PUBLISH method in transaction method, it is possible to use ISO/IEC 20922 which defines Client Server publish/subscribe messaging transport protocol, i.e. MQTT;
- To support near real-time communication, it is possible to use the IEEE 802.1 series which defines TSN services. TSN is a layer 2 protocol that supports low latency, low delay variation, low packet loss. The participating system/devices need to synchronize time, perform traffic shaping through scheduling in order to reduce switching time which leads to reduction of communication time. It is possible to set priority to data to be delivered with different precedence. Control data or data related to safety can be set with high priority;
- Regarding security, security algorithms to consider are PSK, ECDHE, CBC, CCM, SHA, RSA, etc.;
- It is difficult to apply security for services that are overwhelmed with data such as edge computing, cloud, IoT data. Diffie–Hellman key exchange protocol are used for such services.

A.2.4 Implementation options for IE-D

The implementation options for IE-D are as follows:

- OME may support global protocols such as MTConnect, OPC-UA, administration shell, etc. In this case OME is integrated with the DCDCE, thus, IE-D is not needed;
- Regarding support of local network, OME can support proprietary network or Industrial Ethernet protocol (e.g., CFX, EtherCAT, Ethernet/IP, Profinet, Modbus, RAPIENet);
- Regarding support of adaptation, DCDCE will need to interface with the OME and support adaptation/translation of the protocols used in proprietary network or Industrial Ethernet with the global protocols;
- Some legacy equipment or devices may not have networking capability. It is possible to use various sensors to collect some information. For example, it is possible to estimate operational status of the equipment with thermal sensor, vibration sensor, sound sensors, electric current, etc.

A.3 Mapping of Digital Twin with source data

Figure A.2 describes the mapping of Digital Twin with various types of source data.

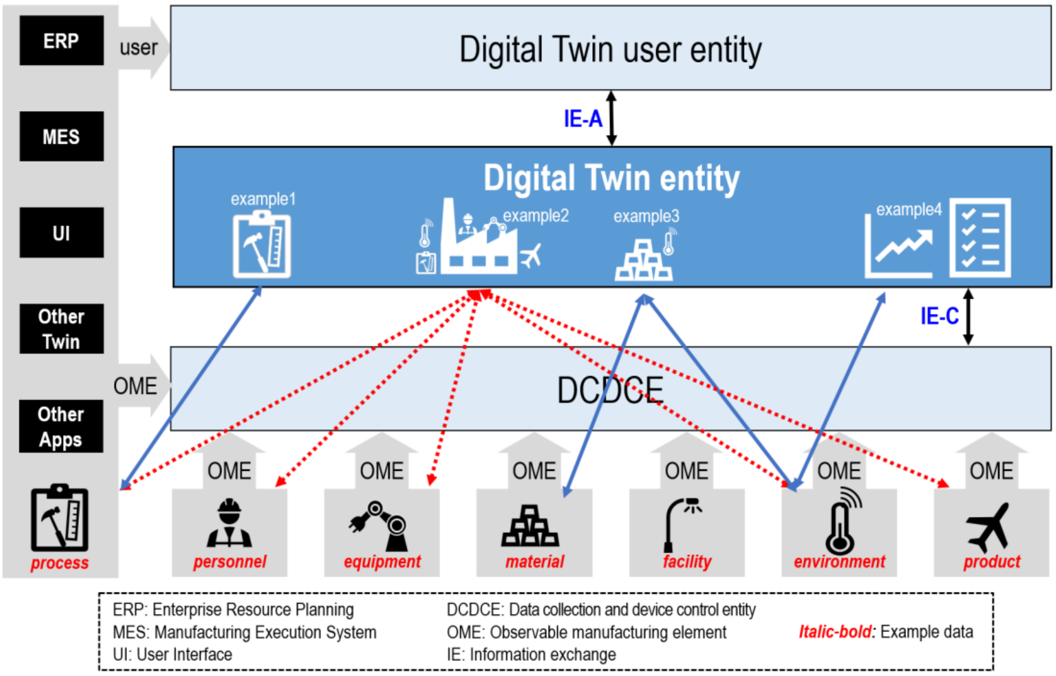


Figure A.2 — Mapping of Digital Twin with source data

Figure A.2 shows four examples of Digital Twin in Digital Twin entity and its mapping with various types of source data. The examples are described as follows:

– Digital Twin can be a twinning of application using source data from various manufacturing application (i.e., process) such as UI, MES, ERP as shown in example1 of Figure A.2. Application (e.g., UI, MES, ERP) can be the Digital Twin user entity and the OME (provider of source data). For application acting as a Digital Twin user entity, application can utilize results from the Digital Twin entity for planning and analysis. Application acting as an OME provides data regarding manufacturing process such as product planning, manufacturing execution, quality test results;

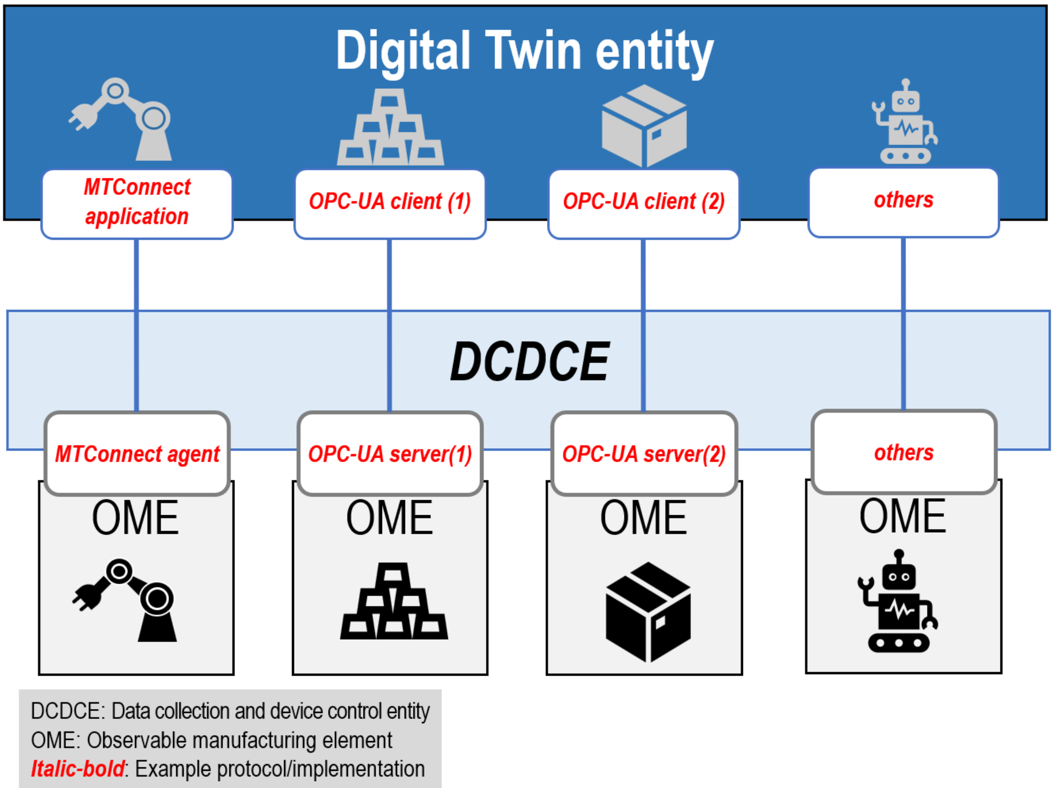
– Digital Twin can be twinning of manufacturing operations as shown in example2 of Figure A.2. It combines data from various OMEs such as process, personnel, equipment, environment, product, etc. Digital Twin entity needs to carefully maintain consistency on data received from multiple OMEs by observing and coordinating data with regards to time, location, action, condition, state, etc.;

– Digital Twin can be twinning of single device of OME as shown in example3 of Figure A.3. It can also use data from the environment (e.g., sensors) for more accurate presentation of the Digital Twin;

– Digital Twin can be twinning of trends or check-list as shown in example4 of Figure A.3. It can use data from environment (e.g., sensors).

613 ## A.4 Structure of multiple DCDCE and multiple OME

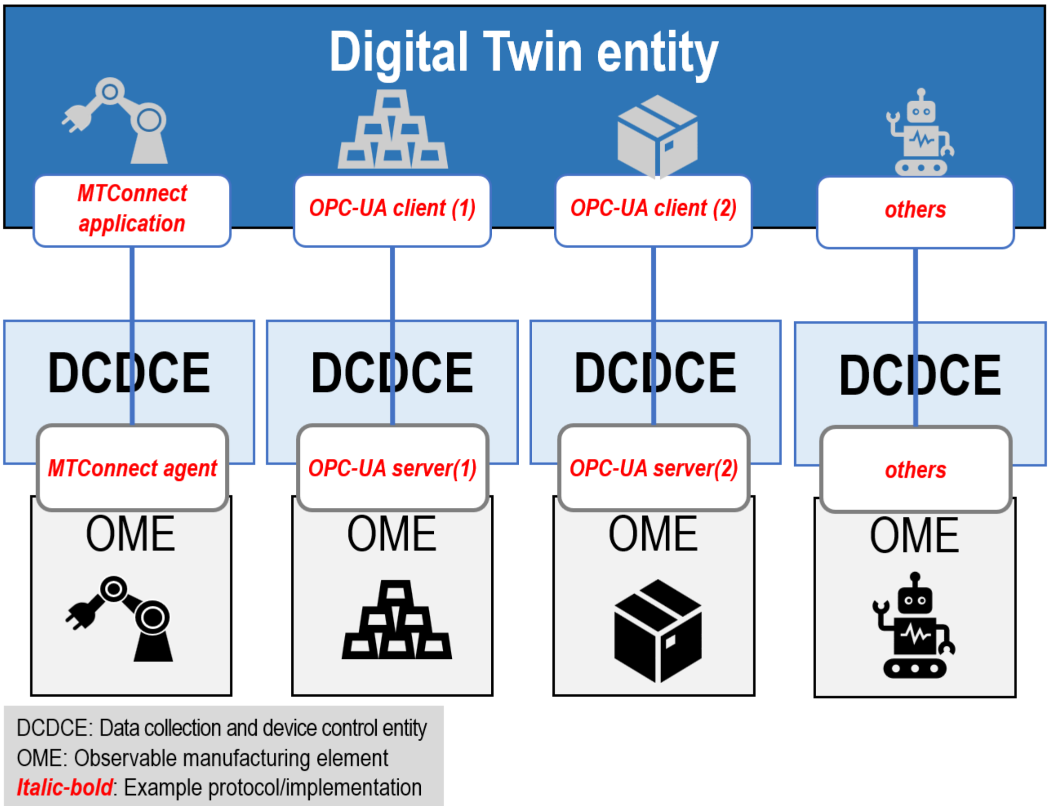
614 Figure A.3 describes how to structure DCDCE with multiple OMEs using different types of protocols.
615 DCDCE can control and manipulate multiple OMEs. The OMEs can use same or different types of
616 protocols.



617

618 **Figure A.3 — DCDCE controlling multiple OMEs**

619 Figure A.4 describes how to structure Digital Twin entity with multiple DCDCEs using different types of
620 protocols. The Digital Twin entity can control and manipulate multiple DCDCEs.

621 

622 **Figure A.4 — Digital Twin entity controlling multiple DCDCEs**

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