INTERNATIONAL STANDARD

ISO 23247-4

First edition
2021-10

Automation systems and integration — Digital twin framework for manufacturing —

Part 4: Information exchange

Systèmes d'automatisation industrielle et intégration — Cadre technique de jumeau numérique dans un contexte de fabrication —

Partie 4: Échange d'informations

Reference number
ISO 23247-4:2021(E)

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

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

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

A digital twin assists with detecting anomalies in manufacturing processes to achieve functional objectives such as real-time control, predictive maintenance, in-process adaptation, Big Data analytics, and machine learning. A digital twin monitors its observable manufacturing element by constantly updating relevant operational and environmental data. The visibility into process and execution enabled by a digital twin enhances manufacturing operation and business cooperation.

The type of manufacturing supported by an implementation of the ISO 23247 framework depends on the standards and technologies available to model the observable manufacturing elements. Different manufacturing domains can use different data standards. As a framework, this document does not prescribe specific data formats and communication protocols.

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

— ISO 23247-1: General principles and requirements for developing digital twins in manufacturing;

— ISO 23247-2: Reference architecture with functional views;

— ISO 23247-3: List of basic information attributes for the observable manufacturing elements;

— ISO 23247-4: Technical requirements for information exchange between entities within the reference architecture.

Figure 1 shows how the four parts of the series are related.

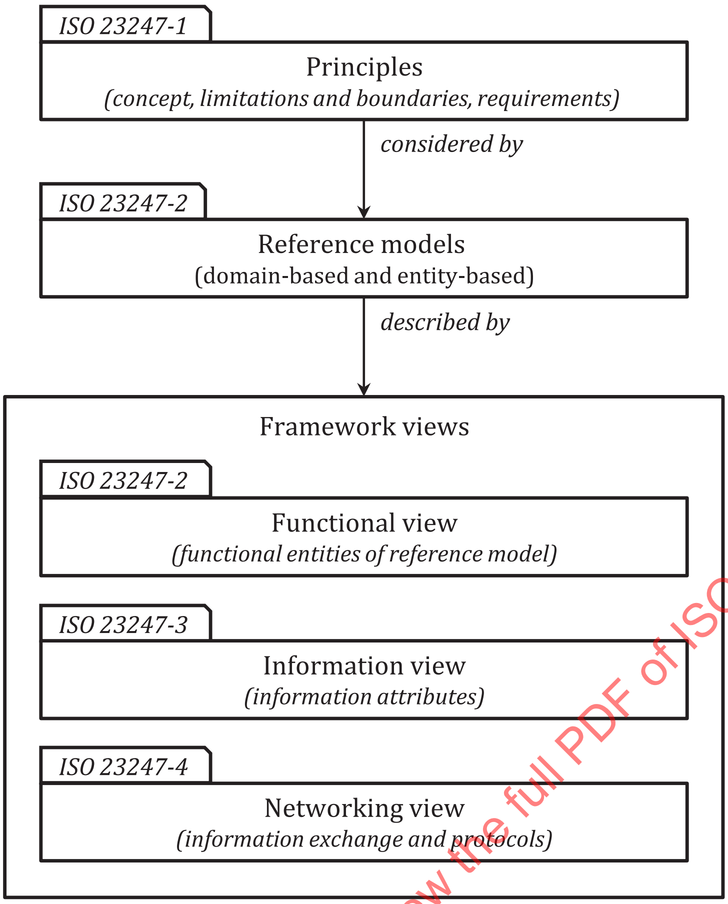


Figure 1 — ISO 23247 series structure

Annexes A to E provide use cases that demonstrate the digital twin framework for manufacturing.

The use cases are in the discrete manufacturing domain and the digital twins are modelled using the ISO 10303 series. In other domains, different standards and technologies can be used. For example, in oil and gas, the digital twins may be modelled using the ISO 15926 series, and for building and construction, the digital twins may be modelled using the ISO 16739 series.

Automation systems and integration — Digital twin framework for manufacturing —

Part 4: Information exchange

1 Scope

This document identifies technical requirements for information exchange between entities within the reference architecture.

The requirements for information exchange in the following networks are within the scope of this document:

— user network that connects the user entity and the digital twin entity;

— service network that connects sub-entities within the digital twin entity;

— access network that connects the device communication entity to the digital twin entity and to the user entity;

— proximity network that connects the device communication entity to the observable manufacturing elements.

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 framework for manufacturing — Part 1: Overview and general principles*

ISO 23247-2, *Automation systems and integration — digital twin framework for manufacturing — Part 2: 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 terminology databases for use in standardization at the following addresses:

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

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

3.1
device communication entity
(set of) system or device providing device communication

EXAMPLE A cell controller sending instructions to the devices in a manufacturing cell, and collecting results from sensors on the devices.

[SOURCE: ISO 23247-2:2021, 3.4]

3.2
digital twin entity
(set of) system(s) providing functionalities for the digital twins such as realisation, management, synchronization, and simulation

EXAMPLE A system providing simulation, synchronization, and data analytics for a manufacturing cell.

[SOURCE: ISO 23247-2:2021, 3.6]

3.3
user entity
human users, applications, and systems that use the services provided by the digital twin entity

EXAMPLE An enterprise resource planning (ERP) system that uses the application programming interfaces (APIs) provided by a digital twin application to update the current status of resources in its database.

[SOURCE: ISO 23247-2:2021, 3.8]

3.4
visualization
<computer graphics> use of computer graphics and image processing to present models or characteristics of processes or objects for supporting human understanding

Note 1 to entry: Example: A visual display of a computerized numerical control (CNC) machine milling an aluminium block.

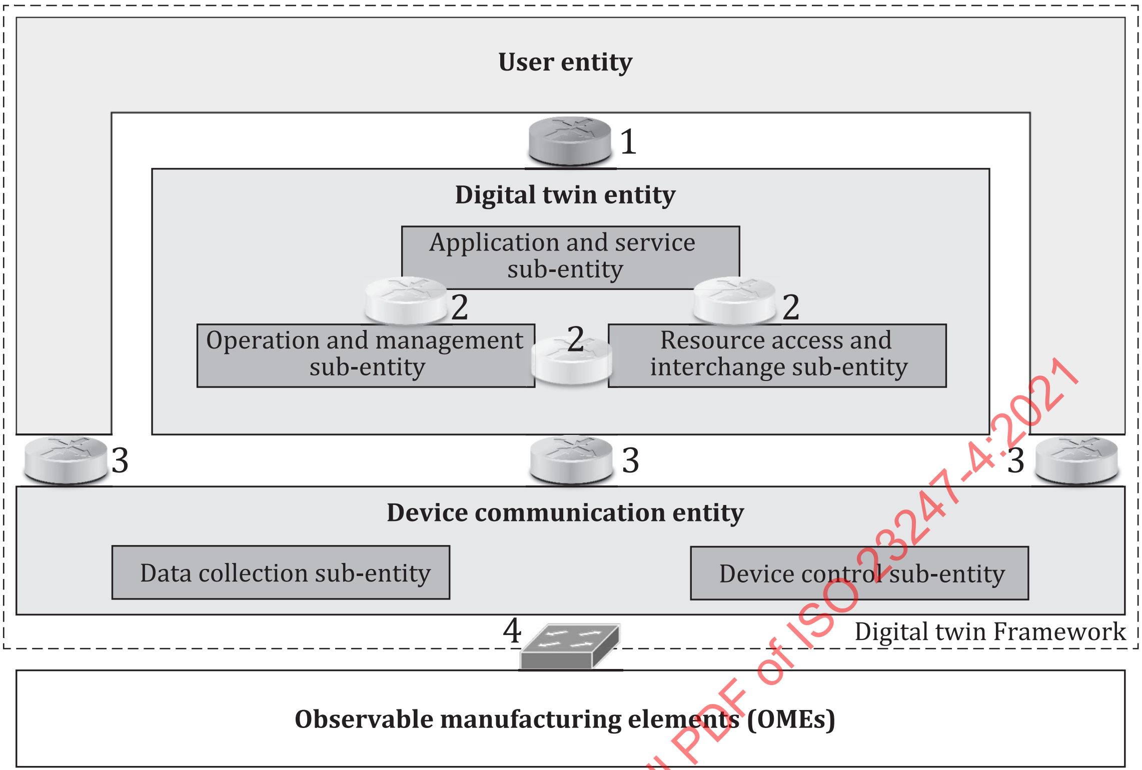
[SOURCE: ISO/IEC 2382:2015, modified — Note 1 to entry changed to address manufacturing examples. Note 2 to entry and Note 3 to entry deleted.]

4 Networking view of the digital twin reference models

4.1 Overview

ISO 23247-2 defines reference models of the digital twin framework for manufacturing, and a functional view of those reference models. This document defines a networking view. The networking view shall apply to the reference models given in ISO 23247-2.

Figure 2 shows the four types of communication networks that are used to connect the entities described in the reference models of ISO 23247-2.



Key

1 user network

2 service network

3 access network

4 proximity network

Figure 2 — Networking view of digital twin reference models

4.2 User network

The user network connects the user entity with the digital twin entity. Through this network, the user entity makes use of the digital twin instances managed by the digital twin entity.

The user network can be either public Internet or private intranet.

4.3 Service network

The service network connects the operation and management sub-entity, application and service sub-entity, and resource access and interchange sub-entity. The service network is typically a wired network running IP-based protocols.

If the digital twin entity is implemented as a single private system, then a service network is not necessary.

4.4 Access network

The access network connects the device communication entity with the digital twin entity and the user entity. The data collection sub-entity transmits data collected from the OMEs to the digital twin entity. The device control sub-entity transmits commands from the user entity or the digital twin entity to control the OMEs.

The access network can be a wired communication network such as local area network (LAN) or wireless communication network such as wireless LAN (WLAN) and mobile (cellular) network. The access network generally adopts IP-based communication protocols regardless of communication type.

4.5 Proximity network

The proximity network connects the device communication entity with the OMEs. Through this network, the device communication entity transmits commands to OMEs that are industrial devices, and receives results from OMEs that are industrial sensors.

The proximity network can be an Industrial Ethernet or a proprietary network with a specialized configuration. Some networks use protocols other than IP. However, if an OME is physically attached or integrated into the device communication entity then the proximity network is not necessary.

5 Requirements for information exchange in the user network

5.1 Overview

The user network shall enable the exchange of information between the user entity and the digital twin entity. The information shall be exchanged to enable services and applications such as visualization, process monitoring, statistical analysis, and simulation. The information is defined in ISO 23247-3.

5.2 Provisioning

The user network shall enable the delivery of information to configure a digital twin to an initial state.

EXAMPLE 1 The digital twin of a product is provisioned at the start of its life from information contained in Product lifecycle management (PLM). This information can be product requirements, 3D models, configuration, simulation models, and traceability.

EXAMPLE 2 The digital twin of a work cell is provisioned at the start of its life from information in PLM or other data sources. This information can be kinematics, capacity, capability, certification, and calibration.

EXAMPLE 3 The digital twin of a process is provisioned at the start of its life from information in PLM or other data sources. This information can be high-level and low-level process plans, production schedule, and manufacturing requirements.

5.3 On-demand status acquisition

The user network shall enable the delivery of information on the current state of the OMEs as represented by its digital twin.

The user network shall enable the delivery of information on the historical state of the OMEs as represented by its digital twin.

EXAMPLE 1 A user entity queries a digital twin entity, so that it can show the current status of a machine by creating a visualization of the current geometry of a part.

EXAMPLE 2 A user entity queries a digital twin entity, so that it can dynamically predict the remaining life for a cutting tool by analysing its previous machining activities.

5.4 Standardized method for information exchange

The user network shall use standardized methods for exchanging information.

NOTE As described in A.2.1, examples for standardized protocol include REST and HTTP.

5.5 Verification of exchanged digital models

The standardized method for information exchange should include methods for verifying the syntax and semantics of the exchanged model and validating its contents.

NOTE As described in A.2.1, examples of information models with methods for checking syntax and semantics include STEP and QIF.

5.6 Security

The user network shall maintain security and privacy of the digital twin.

NOTE Standard such as IEC 62443 define a protocol for secure communication.

5.7 Synchronization

The user network shall enable applications to operate on digital models that have been appropriately synchronized. The rate of synchronization depends on the application.

5.8 Exchange of digital models

The user network shall enable exchange of information about the digital representation of the OMEs. The communication shall allow applications to operate on common models of the OMEs. Depending on the application, it is possible that the types of OMEs shown in Figure 3 need to be modelled for information exchange.

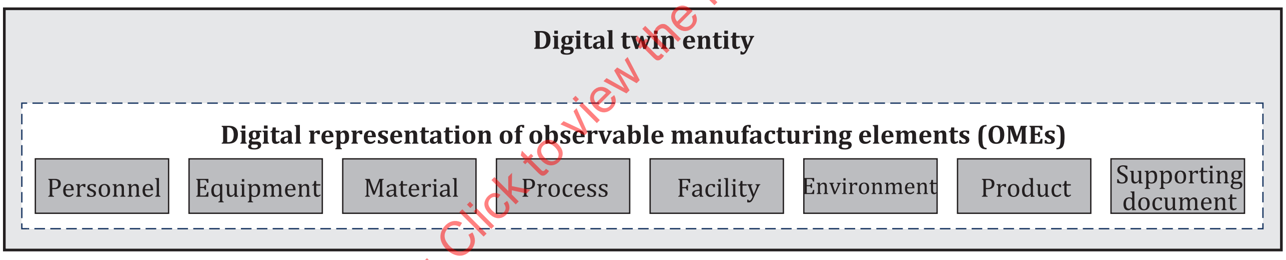


Figure 3 — Type of digital models for exchange

NOTE Several standards define information for one or more of the OME types but no single standard has been identified for all types of OME at the time of publication.

6 Requirements for information exchange in the service network

The Service network is used to transmit information between sub-entities of the digital twin entity. As such, this network can be private to a particular implementation of the digital twin entity and does not need to be defined by this document.

7 Requirements for information exchange in access network

7.1 Overview

The access network connects the device communication entity to other entities. The device communication entity collects information about the OMEs as they operate using an appropriate streaming protocol. The device communication entity controls the OMEs by sending commands in a language understood by the OMEs.

7.2 Connectivity

Depending on the circumstances, a connection to the device communication entity may be discovered dynamically using an appropriate protocol or using a fixed network address. In either case, the connection delivers data about the OMEs to the digital twin entity.

EXAMPLE 1 With a fixed network address, an MTConnect agent for a machine tool on the shop floor is published to the network as URL 192.168.0.1:5000. In this case, the digital twin for the machine tool uses this address to listen for changes to its OME.

EXAMPLE 2 With a dynamic network address, an MQTT subscriber discovers the availability of a data stream from the device communication entity responsible for the OMEs and uses the information to update its digital twin.

7.3 Standardized method for communication

The access network shall provide a standardized method for delivering data collected by the device communication entity. The method shall include information sufficient to identify the OMEs, and describe each change that has occurred to a monitored characteristic of the OME.

The access network shall provide a standardized method for delivering data to control the OMEs through the device communication entity.

7.4 Synchronization

The access network shall enable the digital twin to be connected to its OME. The bandwidth and latency shall be sufficient to support the required level of synchronization.

NOTE 1 IEC has defined standards that describe various synchronization methods for industrial enterprises.

NOTE 2 The latency requirements for servicing an urgent fault or alarm are different to those for updating a 3D model.

7.5 Transaction method

The access network shall support any of the three types of transaction methods that follow:

— PULL method: requester requests information from the provider;

NOTE 1 The digital twin entity is the requester and the device communication entity is the provider.

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

NOTE 2 The digital twin entity is the receiver and the device communication entity is the sender.

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

NOTE 3 The digital twin entity is the subscriber and the device communication entity is the publisher.

The PUBLISH method is recommended, when multiple digital twin entities are listening to a single device communication entity.

7.6 Support of mobility

If the network location of the device communication entity changes, then the access network shall maintain the connectivity to its digital twin.

7.7 Security

The access network shall maintain security and privacy of the digital twin.

NOTE Standards such as IEC 62443 define protocols for secure communication.

8 Requirements for information exchange in proximity network

8.1 Overview

The proximity network is an interface between the device communication entity and the OMEs. The proximity network is not necessary if the device communication entity is hosted on the OME.

8.2 Support of local connectivity

The proximity network shall connect the device communication entity to the OMEs using industrial ethernet or a proprietary network.

8.3 Support of adaptation

The proximity network shall support adaptation of data received from OMEs to data that is understood by the device communication entity.

8.4 Support of data volume, transmission efficiency, and storage

The proximity network shall support data volume, transmission efficiency, and storage necessary to transmit information between the device communication entity and OMEs.

Annex A
(informative)

Technical discussion — Implementation options for digital twin framework for manufacturing

A.1 Acronyms used in Annexes A to E

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

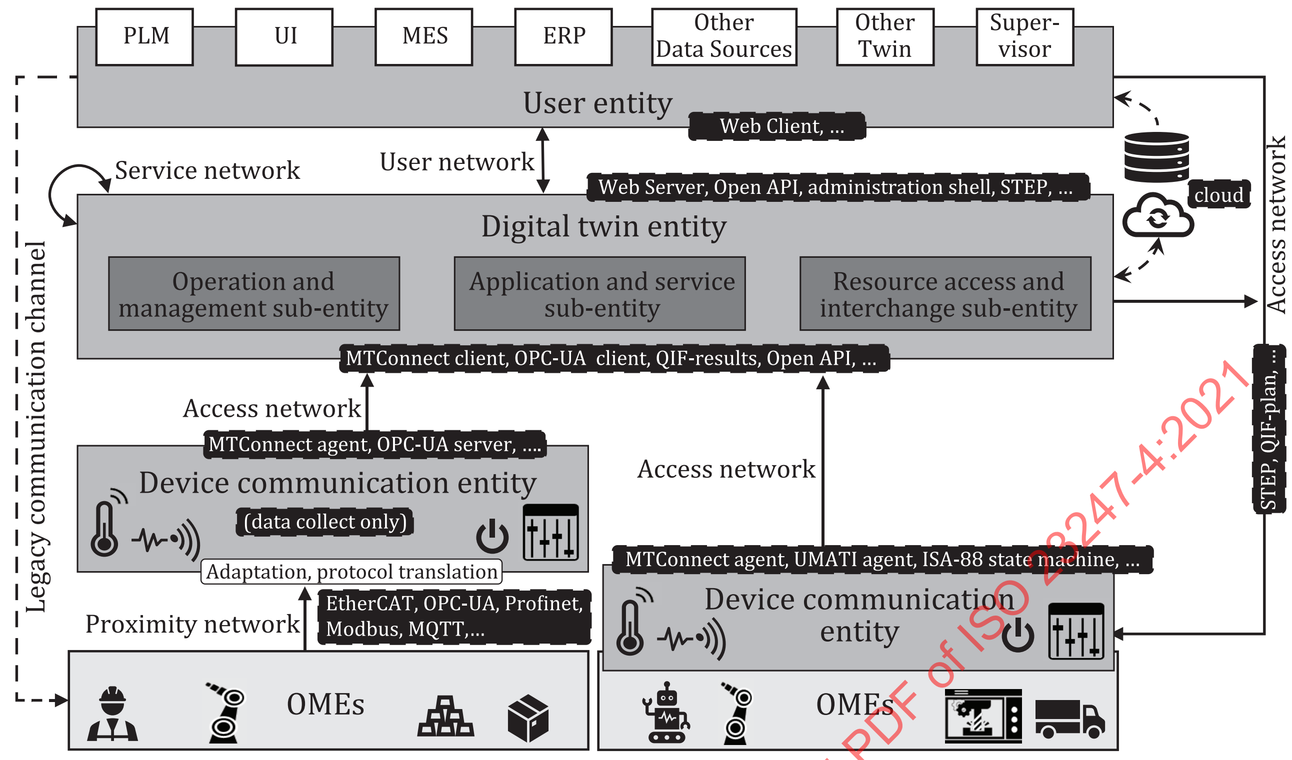
3D PDF	3-dimensional portable document format
AAS	asset administration shell
AES	advanced encryption standard
AMF	additive manufacturing file format
API	application program interface
ASTM	American society for testing and materials
AutomationML	automation markup language
B2MML	business to manufacturing markup language
CAD	computer aided design
CAM	computer aided manufacturing
CBC	cipher-block chaining
CCM	counter with CBC-MAC
CFX	connected factory exchange
COLLADA	collaborative design activity
EASA	European aviation safety agency
ECDHE	elliptic-curve diffie–hellman
EtherCAT	ethernet for control automation technology
FAA	federal aviation administration
FBX	filmbox
HTTP	hypertext transfer protocol
IoT	Internet of Things
IPC	inter-process communication

ISA	international society of automation
JSON	Javascript object notation
JT	Jupiter tessellation
LwM2M	lightweight machine to machine
MES	manufacturing execution system
MOM	manufacturing operations management
MQTT	message queuing telemetry transport
MTConnect	machine tool connect
OCF	open connectivity foundation
OPC-UA	open platform communications - unified architecture
OpenGL	open graphics library
PLC	programmable logic controller
PSK	phase-shift keying
QIF	quality information framework
RAPINet	real-time automation protocols for industrial ethernet
RDF	resource description framework
REST	representational state transfer
RSA	Rivest–Shamir–Adleman
SHA	secure hash algorithm
STEP	STandard for the Exchange of Product model data
STL	standard template library
TSN	time-sensitive networking
WebGL	web graphics library
XML	extensible markup language

A.2 Information exchange examples

A.2.1 General

Figure A.1 shows how information may be exchanged within a digital twin framework using currently available communication protocols.



Key

OME observable manufacturing element

(solid line): within scope of digital twin

(dotted line): out of scope of digital twin

text example protocol/implementation

Figure A.1 — Information exchange examples

There are two OMEs configurations in Figure A.1.

— In the first configuration (i.e. left device communication entity/OMEs), data is collected by the device communication entity through the proximity network and sent to the digital twin entity using the access network. The OMEs are controlled by the user entity through the legacy communication channel. For example, a G-Code file is written from a PLM and loaded into the control by an operator.

— In the second configuration (i.e. right device communication entity/OMEs), data is collected directly by the device communication entity within a single system and sent to the digital twin entity using the access network. For example, a modern CNC control may support direct numerical control for data input, and MTConnect for reporting results.

A.2.2 Implementation options for information exchange in the user network

The implementation options for information exchange in the user network are as follows:

— regarding standardized methods for information exchange, the digital twin entity can provide web services for the user entity using HTTP or REST;

— the digital twin entity can define Open APIs for the user entity. A web interface is one example of an Open API;

— the digital twin entity and the user entity can use a database or a cloud to share or exchange the information;

— the digital twin entity can interface with applications such as PLM, MES, and ERP. The digital twin entity can get manufacturing-related data through interfaces with these applications;

— for applying manufacturing information, the standards that can be used include the IEC 62264 series (i.e. ISA-95) that defines the automated interface between enterprise and control systems. A B2MML is an XML implementation of IEC 62264. The B2MML can be used to extract information on manufacturing (e.g., asset tracking, inventory management) that can be applied to the digital twin. The ISO 16100 series characterizes software-interfacing requirements enabling the interoperability among manufacturing software tools (modules or systems). The ISO 18828 series defines information for seamless production planning;

— for supporting visualization, the standard that can be used include ISO 14306 (i.e. JT). The ISO 14306 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;

— CAD/CAM information can be used to create the digital model of the OMEs. The standards that can be used include ISO 10303-242 (i.e. STEP AP242), ISO 10303-238 (i.e. STEP AP238), ISO 10303-239 (i.e. STEP AP239), and IEC 62714 (i.e. AutomationML). Some applications use a factory layout (blueprint) to create an initial digital model of the shop floor. The 3D file format can be used to store information about 3D models. Some popular formats are STL, FBX, and COLLADA. These formats are used in 3D printing, video games, movies, architecture, academia, medicine, engineering, etc.;

— for embedding 3D models in documents, 3D PDF or 3D rendering can be used. A 3D PDF is a PDF file containing 3-dimensional geometry. 3D rendering is the process of converting 3-dimensional models into 2-dimensional images on a computer or document;

— for providing graphical information through the web, WebGL or OpenGL can be used. WebGL is a JavaScript API for rendering 2D/3D graphics; OpenGL is an API for rendering 2D/3D graphics. In its modern form, OpenGL is a cross-platform library for interfacing with programmable GPUs for the purpose of rendering real-time 3d graphics. Its use is common in games, CAD, and data visualization applications.

— for describing a digital twin model, asset administration shell (AAS) can be used, which is a common meta-model that is used to describe assets in various format such as JSON, XML, and RDF;

— for supporting verification, the standard that can be used include ISO 23952 (i.e. QIF). ISO 23952 is an XML based standard that defines, organizes, and associates quality information. A digital twin can be synchronized with measured values. The accuracy of the predictive results can be increased through data analytics of the QIF measured values.

A.2.3 Implementation options for information exchange in the access network

The implementation options for information exchange in the access network are as follows:

— regarding standardized method for information exchange, a user entity can access and manipulate OMEs using protocols such as MTConnect and OPC-UA;

— the user entity can access and manipulate IoT devices (e.g., sensors, actuators) using protocols such as OPC-UA, OCF, LwM2M, and oneM2M. The IoT protocols have defined various data formats that are exchanged in the protocols;

— for supporting synchronization, a standardized data format such as ISO/ASTM 52915 (i.e. AMF) can be used. ISO/ASTM 52915 is an XML-based format for describing objects for additive manufacturing process such as 3D printing;

— for supporting PUBLISH method, the ISO/IEC 20922 (i.e. MQTT), which defines Client Server publish/subscribe messaging transport protocol, can be used;

— for supporting near real-time communication, the standards that can be used include the IEEE 802.1DF, IEC/IEEE 60802. These standards define TSN services for service provider network and for industrial automation. The TSN is a layer 2 protocol that supports low latency, low delay variation, and low packet loss;

— regarding security, algorithms that may be used include PSK, ECDHE, CBC, CCM, SHA, and RSA;

— if it is difficult to apply security for services that are overwhelmed with data such as edge computing, cloud, and IoT data, then the Diffie–Hellman key exchange protocol can be used.

A.2.4 Implementation options for information exchange in the proximity network

The implementation options for information exchange in the proximity network are as follows:

— if the OME already supports protocols such as MTConnect or OPC-UA, then the proximity network is not needed;

— to support local connectivity, the OME can be connected to the proprietary network or the industrial ethernet (e.g., EtherCAT, Ethernet/IP, Profinet, Modbus, RAPIENet);

— networked sensors can be used to collect various types of information. For example, the operational status of equipment may be monitored with a thermal sensor, a vibration sensor, a sound sensor, etc.

Annex B
(informative)

Dynamic scheduling use case

B.1 Overview

Table B.1 describes the example using a template developed by ISO and IEC.

Table B.1 — Summary of the example on dynamic scheduling

ID	Case number 1
Use case name	Dynamic scheduling of tasks for multiple robots in a manufacturing cell
Application field	Smart manufacturing
Life cycle stage(s)/ phase(s) coverage	Production
Status	In-operation
Scope	Automated manufacturing process adjustment and tracking based on variable conditions of assembly for a multiple robot manufacturing cell
Initial (Problem) Situation	Manufacturing process requirements can vary based on condition of assembly of incoming components. Manual adjustments of the manufacturing processes are time consuming and create risk that the appropriate manufacturing process does not meet requirements or can be improperly tracked.
Objective(s)	Automatically adjust processes and maintain production records using digital twins
Short description (not more than 150 words)	When large, complex assemblies enter a manufacturing cell, there is a high chance that the incoming state of the assembly will not be nominal (missing components, rework requirements.) Manual adjustments of the manufacturing process are time consuming and increases risk that the adjusted process is non-compliant or not properly tracked. Digital twins applications can: 1) determine feature differences between the assembly digital twin and nominal; 2) adjust manufacturing process requirements based on these feature differences; 3) generate and validate adjusted manufacturing process; 4) monitor the as-manufactured status of the process and assembly.
Stakeholders	Manufacturing shop floor personnel, compliance authorities (FAA, EASA, etc.), and Robot cell vendors
Key technologies	Manufacturing automation for work cells containing multiple robots
Relevant standards	AP238 and AP242 to describe digital twins of the process and product MTConnect to communicate process and assembly state to build digital twins
Standardization needs	ISO 23247 digital twin framework for manufacturing to describe how the standards inter-operate on the shop floor
Remaining issues and future works	Adoption of the standards by equipment vendors to ensure seamless plug and play on the shop floor Definition of algorithms/methods for collision avoidance in dynamic environments

B.2 Operational sequences

B.2.1 Process flow

Figure B.1 shows the process flow of the dynamic scheduling of tasks for multiple robots.

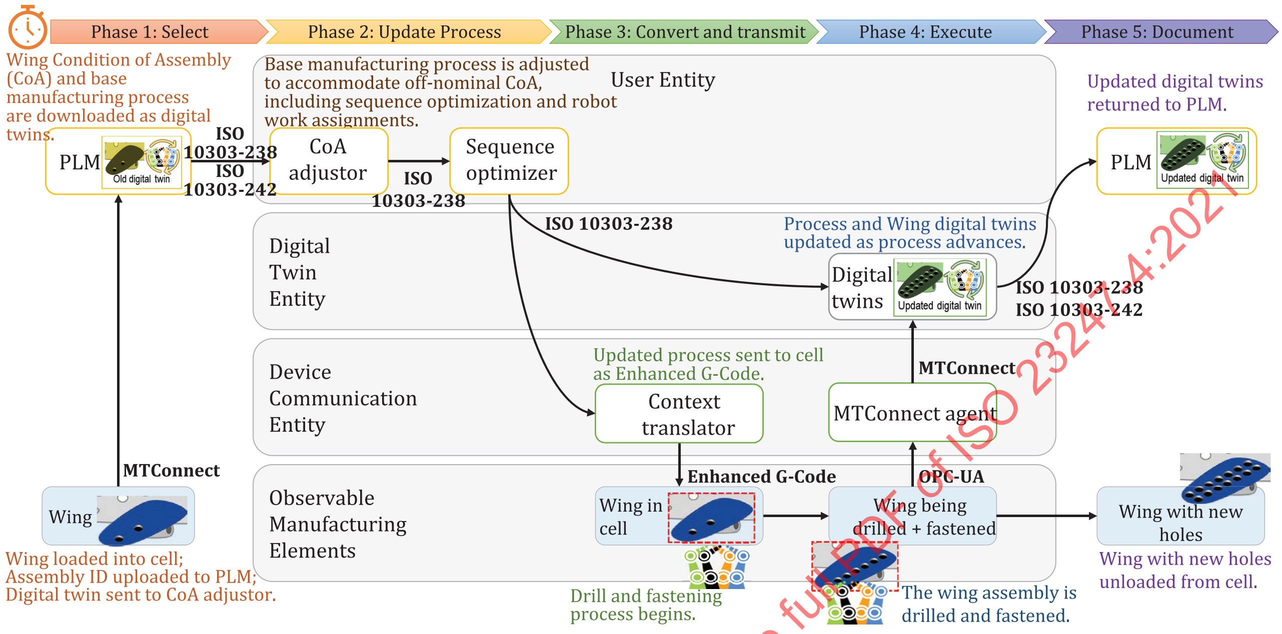


Figure B.1 — Process flow of dynamic scheduling

B.2.2 Phase 1: Select

— Step 1: A wing assembly is physically loaded into the robotic manufacturing cell. The supervisory control is made aware of the assembly type and its instance by use of an Assembly ID.

— Step 2: The supervisory control requests the appropriate Process digital twin (in AP238 format), wing assembly digital twin (in AP242 format), and process requirements from PLM through MOM. Once this is complete, the supervisory control knows the condition of assembly (CoA) to be drilled, and the base process to be executed.

B.2.3 Phase 2: Update process

— Step 1: The supervisory control, using the CoA adjuster, determines which holes do not need to be drilled, based on the wing assembly digital twin (in AP242 format). It then deactivates the related drilling working steps in the process digital twin (in AP238 format).

— Step 2: The sequence optimizer then balances and divides the drilling working steps between the four robots in the manufacturing cell.

— Step 3: The sequence optimizer then optimizes the drilling sequence for each individual robot.

— Step 4: The process digital twin simulates the drilling process and checks for collisions and that all appropriate holes are drilled.

— Step 5: The updated manufacturing process is sent to the context translator.

B.2.4 Phase 3: Convert and transmit

— Step 1: The context translator extracts relevant context (e.g., workplan, working step, and process to hole mapping). The context translator then inserts the relevant context into a standardized implementation of the robots' native programming language (rapid/enhanced rapid).

— Step 2: The enhanced rapid data is transmitted to the manufacturing cell.

— Step 3: The enhanced rapid data is distributed to the individual robots and the manufacturing process is begun.

B.2.5 Phase 4: Execution

— The robots report joint motion and significant execution progress (e.g., holes drilled) to the cell controller using OPC-UA. This data is converted to MTConnect.

— The MTConnect data stream enables the digital twin entity to continuously update the wing assembly and process digital twins. This information includes robot joint motion as well as working step completions.

B.2.6 Phase 5: Document

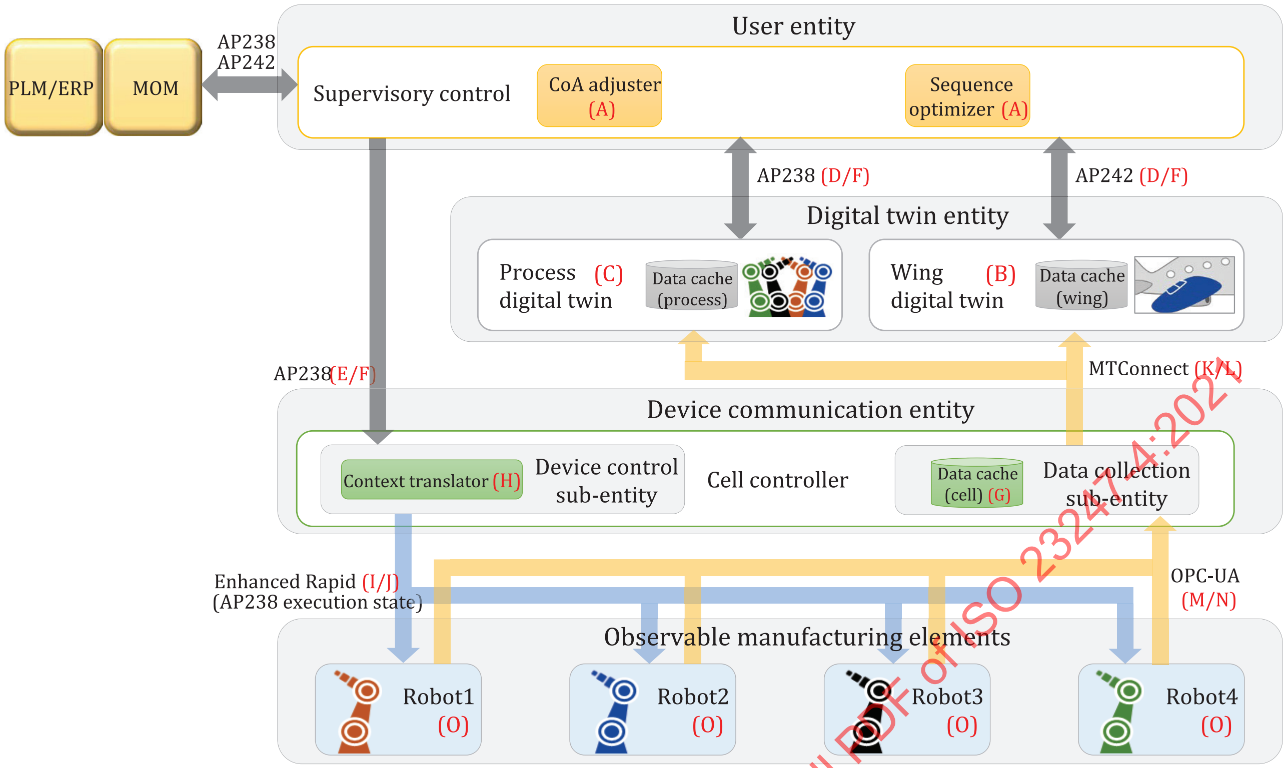
— The updated wing assembly and process digital twins are uploaded back to PLM through MOM. These digital twins are then used as the CoA for downstream processes and reporting.

— The wing assembly, now containing new holes, is unloaded from the manufacturing cell.

B.3 Mapping to the framework

B.3.1 Overview

Figure B.2 shows how the example may be implemented according to the framework.



Key

Models

product/process

State Stream

plunge complete, etc.

Instructions

G-Codes, etc.

Figure B.2 — Dynamic scheduling of robots

B.3.2 Implementation using framework

Implementation of dynamic scheduling use case with to the framework is in Table B.2 with tags shown in Figure B.2.

Table B.2 — Implementation of dynamic scheduling use case using framework

Tag	Role in use case	ISO 23247 name	ISO 23247 reference	Implementation technology	Comment
A	Supervisory control	User entity	ISO 23247-2:2021, 5.3.4	Windows executable using STEP modules	Provides interface to PLM through MOM. Optimizes process based on CoA.
B	Wing digital twin	Digital twin entity	ISO 23247-2:2021, 5.3.3	Windows executable using STEP modules	Synchronizes process wing digital twin with OME using state stream. Presents wing digital twin in AP242 at completion.

Table B.2 *(continued)*

Tag	Role in use case	ISO 23247 name	ISO 23247 reference	Implementation technology	Comment
C	Process digital twin	Digital twin entity	ISO 23247-2:2021, 5.3.3	Windows executable using STEP modules	Synchronizes process digital twin with OME using state stream. Presents process digital twin in AP238 at completion.
D	Models communications (1)	User network	4.2	intranet	Provisions and retrieves wing and process digital twins when manufacturing is complete.
E	Models communications (2)	Access network	4.3	intranet	Sends adjusted manufacturing process to cell controller.
F	Exchange model (of OMEs)	Digital twin representations	ISO 23247-3:2021, Clause 5	AP242, AP238	Initial and synchronized digital twin representations for the wing assembly and process.
G	Data cache (cell)	Data pre-processing FE	ISO 23247-2:2021, 6.2.1.2	MTConnect agent	Caches process state information to assure reliable update of wing and process digital twins.
H	Context translator	Data translation FE	ISO 23247-2:2021, 6.5.3	Windows executable using STEP modules	Converts AP238 into RAPID using Enhanced Rapid conventions. In this use case, the data translator FE is a cross-system entity implemented in the device control sub-entity.
I	Instructions communications	Proximity network	4.5	Industrial ethernet	Transfers Enhanced RAPID commands from Cell Controller to Robots.
J	Instructions	Requirements for information exchange in proximity network	Clause 8	Enhanced RAPID	Process instructions using a standard implementation of the robots' native language "RAPID".
K	State stream communications (1)	Access network	4.4	MTConnect	Transfers state of robots to wing and process digital twins.
L	State stream (1)	Requirements for information exchange in access network	Clause 8	MTConnect	Robot state, including joint condition and process state.
M	State stream communications (2)	Proximity network	4.5	OPC-UA	Transfers state of robots to cell controller.
N	State stream (2)	Requirements for information exchange in proximity network	Clause 8	OPC-UA	Robot state, including joint condition and process state.
O	Robots 1-4	Observable manufacturing element	ISO 23247-2:2021, 3.2	ABB robotics	Out of scope for digital twin framework.

B.3.3 Mapping of wing digital twin to digital twin entity

Implementation of wing digital twin mapping to the digital twin entity is shown in Figure B.3 and Table B.3.

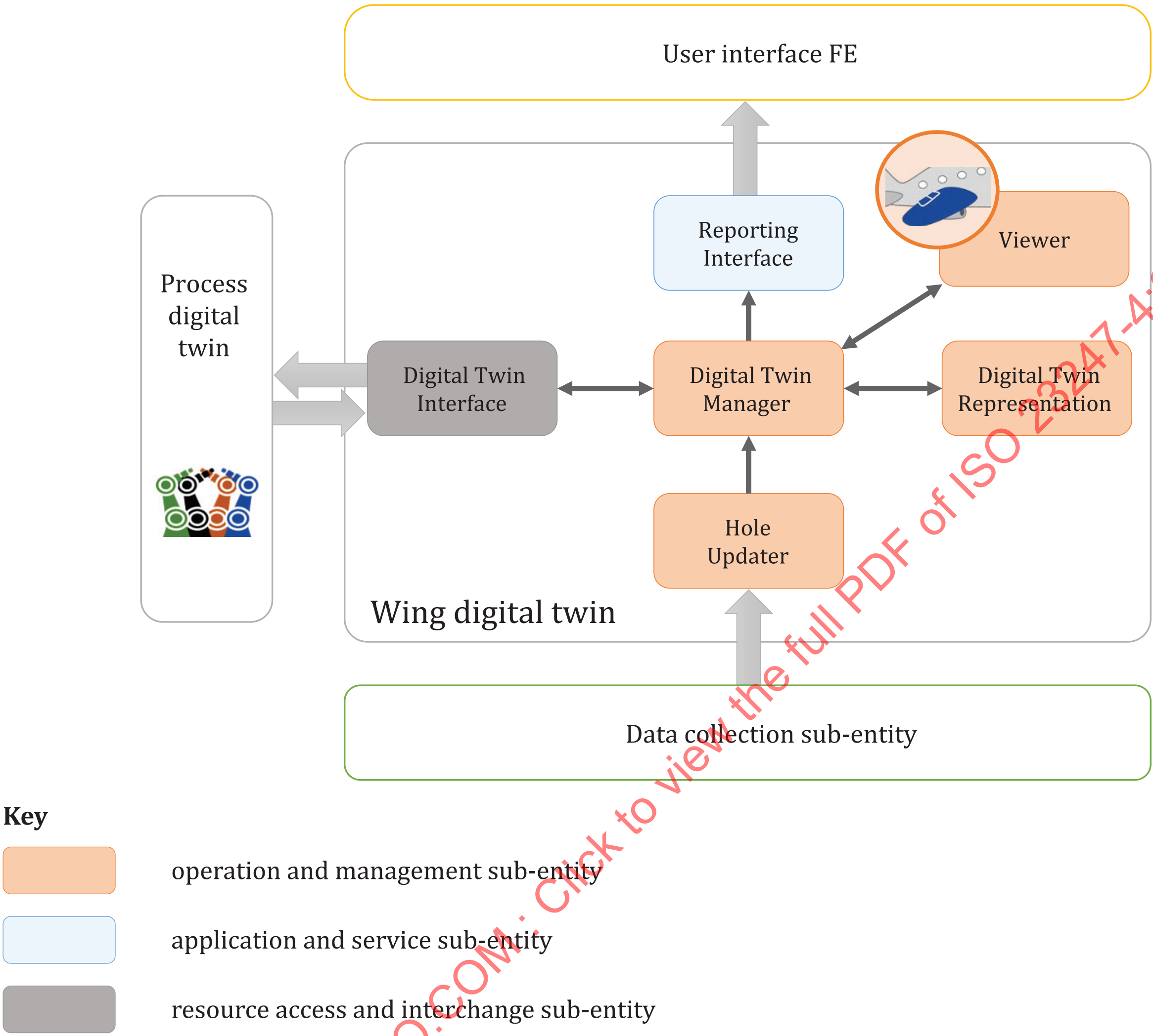


Figure B.3 — Implementation mapping of wing digital twin to digital twin entity

Table B.3 — Mapping of wing digital twin to functional entity

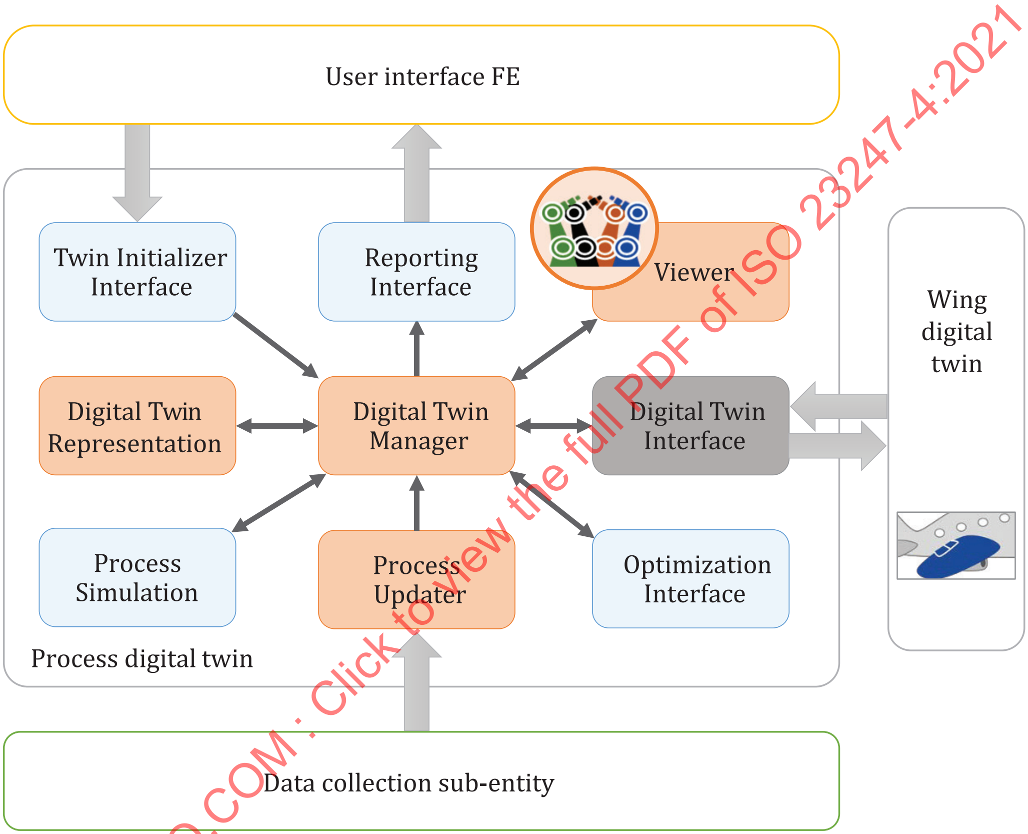
Role in digital twin entity	Functional entity	ISO 23247-2 reference	Data type	Comment
Reporting interface	Reporting FE	ISO 23247-2:2021, 6.3.2.3	AP242	Interface to User Interface FE for CoA of the wing structure.
Digital twin interface	Peer Interface FE	ISO 23247-2:2021, 6.3.3.4	AP242, AP238	Synchronizes wing and process digital twin.
Viewer	Presentation FE	ISO 23247-2:2021, 6.3.1.2	AP242, Modern OpenGL	Displays wing structure CoA as it changes.
Digital twin manager	Maintenance FE	ISO 23247-2:2021, 6.3.1.4	AP242	Manages updating and sharing of digital twin representation.
Digital twin representation	Digital representation FE	ISO 23247-2:2021, 6.3.1.3	AP242	Contains the digital model of the wing structure.

Table B.3 *(continued)*

Role in digital twin entity	Functional entity	ISO 23247-2 reference	Data type	Comment
Hole updater	Synchronization FE	ISO 23247-2:2021, 6.3.1.1	MTConnect, AP238	Updates the digital model of the wing structure as holes are drilled.

B.3.4 Mapping of process digital twin to digital twin entity

Implementation of process digital twin mapping to the digital twin entity is shown in Figure B.4 and Table B.4.



Key

operation and management sub-entity

application and service sub-entity

resource access and interchange sub-entity

Figure B.4 — Implementation mapping of process digital twin to digital twin entity

Table B.4 — Mapping of process digital twin to functional entity

Role in digital twin entity	Functional entity	ISO 23247-2 reference	Data type	Comment
Twin initializer interface	User interface FE	ISO 23247-2:2021, 6.4	AP238, AP242	Interface to User Interface FE for retrieval of the initial/ planned states of the digital twins involved.
Reporting interface	Reporting FE	ISO 23247-2:2021, 6.3.2.3	AP238	Interface to User Interface FE for the drilling process.
Optimization interface	Application support FE	ISO 23247-2:2021, 6.3.2.4	AP238	Interfaces to process optimization tools in the user entity.
Process simulator	Simulation FE	ISO 23247-2:2021, 6.3.2.1	AP238	Simulates execution of drilling process.
Digital twin interface	Peer interface FE	ISO 23247-2:2021, 6.3.3.4	AP242, AP238	Synchronizes wing and process digital twin.
Viewer	Presentation FE	ISO 23247-2:2021, 6.3.1.2	AP238, Modern OpenGL	Displays robots as they drill holes.
Digital twin manager	Maintenance FE	ISO 23247-2:2021, 6.3.1.4	AP238	Manages updating and sharing of digital twin representation.
Digital twin representation	Digital representation FE	ISO 23247-2:2021, 6.3.1.3	AP238	Contains the digital model of the drilling process.
Process updater	Synchronization FE	ISO 23247-2:2021, 6.3.1.1	MTConnect AP238	Updates the as executed digital model of the hole drilling process.

Annex C
(informative)

Advanced metrology use case

C.1 Overview

Table C.1 describes the example using a template developed by ISO and IEC.

Table C.1 — Summary of the example on advanced metrology

ID	Case number 2
Use case name	Advanced metrology
Application field	Smart manufacturing
Life cycle stage(s)/ phase(s) coverage	Production
Status	Prototype
Scope	The digital twin of a part with complex shape is measured to determine precise assembly stack thickness so that the exact lengths for fasteners can be determined, enabling weight reduction.
Initial (Problem) Situation	For complex geometries, the as-built shape varies slightly between instances because of variances in production processes and environmental conditions. For mating assemblies, the variations cause differences to the assembly stack thickness.
Objective(s)	Model digital twins of the as-built geometry with precise thickness for the mating parts so they can be matched with fasteners of exactly the right length.
Short description (not more than 150 words)	An assembly with complex geometries is measured to make an accurate model of the as-built part: 1) verify geometry tolerances; 2) determine precise lengths for fasteners; 3) reduce weight by using less material for fasteners.
Stakeholders	Manufacturing shop floor personnel, compliance authorities (FAA, EASA, etc.)
Key technologies	Automated drilling and fastening of complex structures Automated measurement of layered assemblies
Relevant standards	ISO 10303-242 to describe digital twins of the product assembly ISO 23952 (QIF) to describe measurement plan and measurement results for components MTConnect to communicate process and assembly state to build digital twins
Standardization needs	ISO 23247 digital twin framework for manufacturing to describe how the standards inter-operate on the shop floor
Remaining issues and future works	Adoption of the standards by the metrology vendors to ensure seamless plug and play on the shop floor

C.2 Operational sequences

C.2.1 Process flow

Figure C.1 shows the process flow of the optimization of advanced metrology.

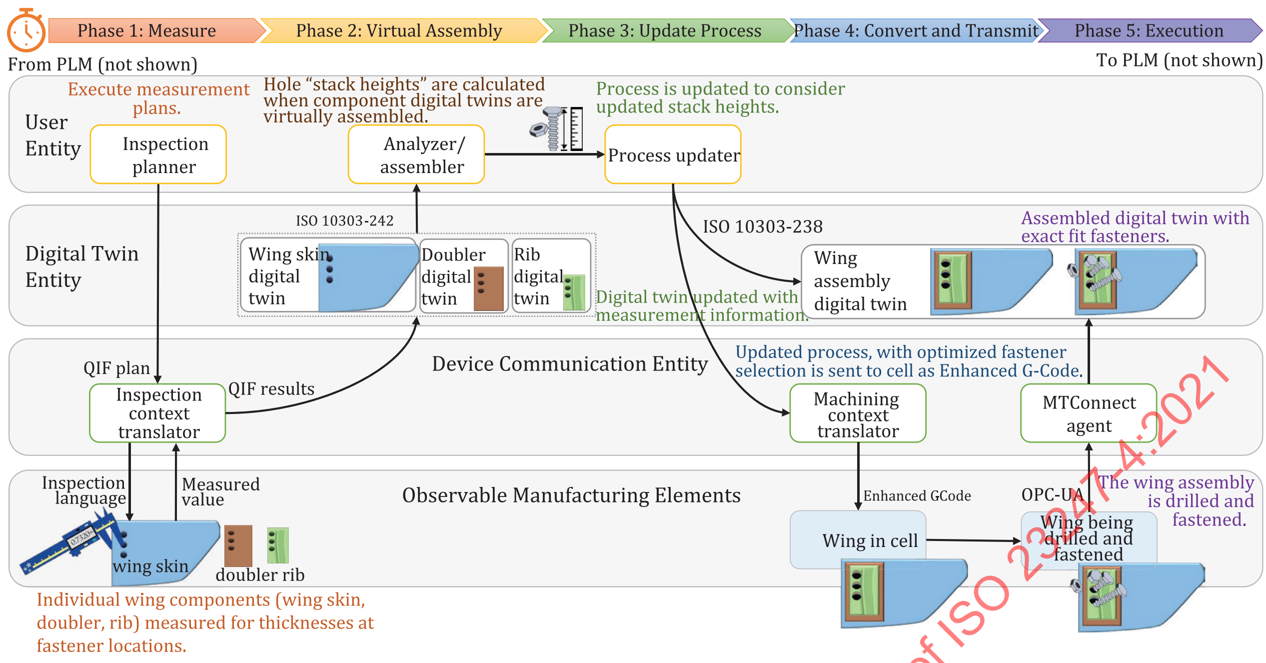


Figure C.1 — Process flow of advanced metrology

C.2.2 Phase 1: Measure

— Step 1: An inspection planner defines an inspection process that measures the thickness of individual wing components (i.e. wing skin, doubler, rib) near their fastener locations. The inspection process is defined as a QIF plan.

— Step 2: The inspection context translator converts the QIF plan into the native language of the measurement equipment.

— Step 3: As the inspection process proceeds, results are translated into QIF results by the Inspection context translator.

— Step 4: The QIF results are used to update digital twins of the individual components.

C.2.3 Phase 2: Virtual assembly

— Step 1: The updated digital twins of the individual wing components are virtually aligned and assembled.

— Step 2: "Stack heights" for each fastener are calculated by adding the thicknesses of each individual wing component at each location where a hole is to be drilled for a fastener to be placed.

C.2.4 Phase 3: Update process

— Step 1: Based on the stack heights determined in Phase 2, optimized fastener selections are determined by matching fastener grip length ranges to the calculated stack heights.

— Step 2: The assembly manufacturing process is updated to assign the optimized fastener assignments to the appropriate hole locations.

— Step 3: The digital twin of the wing assembly is updated to include the optimized fastener assignments.

C.2.5 Phase 4: Convert and transmit

— Step 1: The machining context translator converts the updated process to enhanced G-code.

— Step 2: The enhanced G-code is sent to the wing assembly cell.

C.2.6 Phase 5: Execution

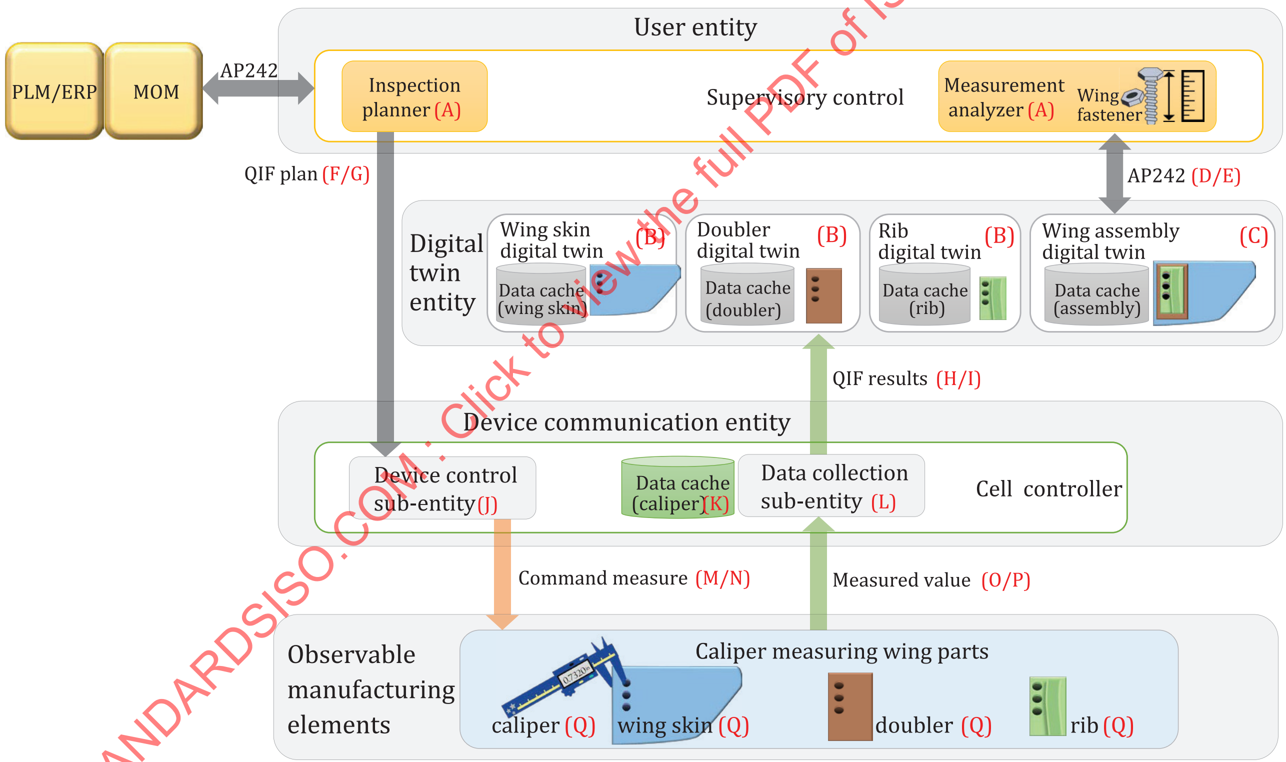
— The wing assembly cell reports execution progress (e.g., holes drilled, fasteners installed) to the MTConnect agent.

— The MTConnect data stream enables the digital twin entity to continuously update the wing assembly digital twins.

C.3 Mapping to the framework

C.3.1 Overview

Figure C.2 shows how the example may be implemented according to the framework.



Key

Models

product/process

Commands

stop/go, etc.

Measurements

hole dimensions, etc.

Figure C.2 — Advanced metrology

C.3.2 Implementation using framework

Implementation of advanced metrology use case with to the framework is in Table C.2 with tags shown in Figure C.2.

Table C.2 — Implementation of advanced metrology use case using framework

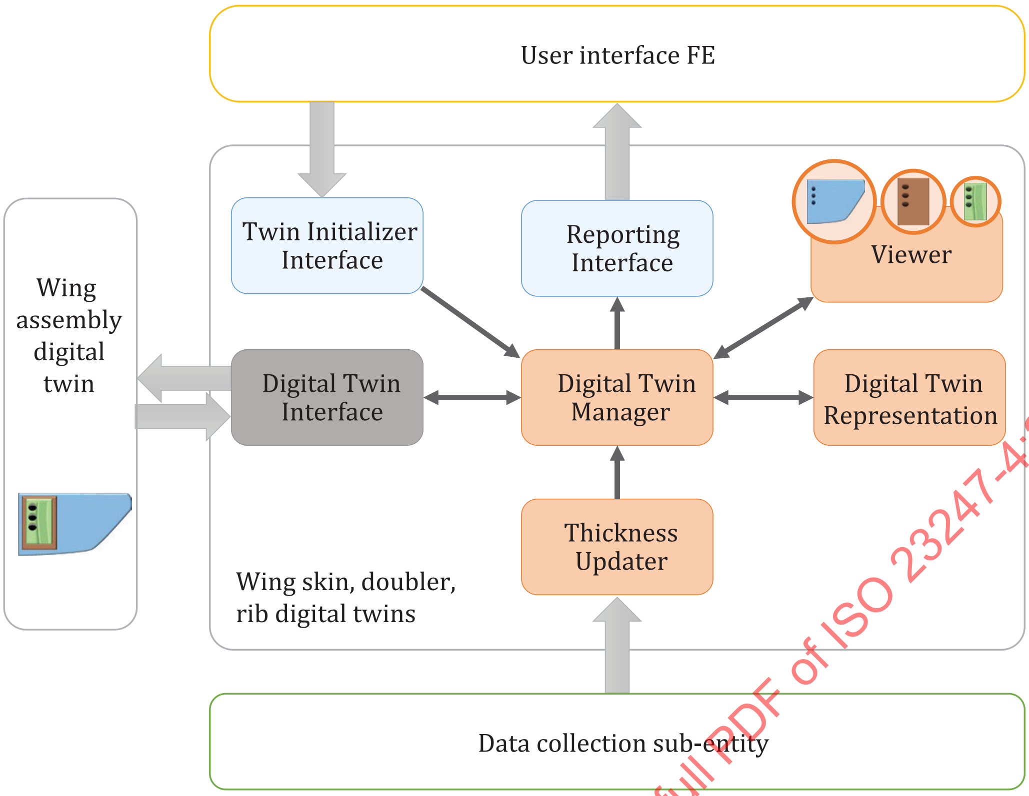
Tag	Use case role	ISO 23247 name	ISO 23247 reference	Implementation technology	Comment
A	Supervisory control	User entity	ISO 23247-2:2021, 5.3.4	Windows executable using STEP and QIF modules	Provides interface to PLM through MOM. Develops inspection plans and analyses measurements.
B	Wing skin, doubler, rib digital twins	Digital twin entity	ISO 23247-2:2021, 5.3.3	Windows executable using STEP modules	Synchronizes process wing skin, doubler, and rib digital twins with OME using state stream. Presents wing skin, doubler, and rib digital twins in AP242 at completion.
C	Wing assembly digital twin	Digital twin entity	ISO 23247-2:2021, 5.3.3	Windows executable using STEP modules	Synchronizes wing assembly digital twin with OME using state stream. Presents process digital twin in AP242 at completion.
D	Models communications	User network	4.2	Intranet	Provisions and retrieves wing skin, doubler, rib, and wing assembly digital twins when manufacturing is complete.
E	Exchange model (of OMEs)	Digital twin representation	ISO 23247-3:2021, Clause 5	AP242	The appropriate model is used for the exchange of the state of wing assembly, wing skin, doubler, and rib.
F	QIF plan Communications	Access network	4.4	Intranet	Transfers QIF inspection plans to cell controller.
G	QIF plan	Requirements for information exchange in access network	Clause 7	QIF	QIF inspection plans to be executed by the cell controller.
H	QIF results communications	Access network	4.4	Intranet	Transfers inspection results from cell controller to Wing skin, doubler, and rib digital twins.

Table C.2 *(continued)*

Tag	Use case role	ISO 23247 name	ISO 23247 reference	Implementation technology	Comment
I	QIF results	Requirements for information exchange in access network	Clause 7	QIF	Inspection results as QIF results to wing skin, doubler, and rib digital twins.
J	Device control sub-entity	Controlling FE	ISO 23247-2:2021, 6.2.2.1	Windows executable using QIF modules	Converts QIF inspection plan to Mitutoyo U-wave format.
K	Data cache (caliper)	Data pre-processing FE	ISO 23247-2:2021, 6.2.1.2	Windows	Caches measurement results to assure reliable update of wing skin, doubler, rib, and wing assembly digital twins.
L	Data collection sub-entity	Data collecting FE	ISO 23247-2:2021, 6.2.2.2	Windows executable using QIF modules	Update measurement results (QIF results) to wing skin, doubler, rib, and wing assembly digital twins.
M	Command measure	Requirements for information exchange in proximity network	Clause 8	Mitutoyo U-wave	Commands to caliper/user.
N	Command measure (Communications)	Proximity network	4.5	Bluetooth	Transfers measurement commands to caliper/user.
O	Measured value	Requirements for information exchange in proximity network	Clause 8	Mitutoyo U-wave	Results from caliper measurements.
P	Measured value (Communications)	Proximity network	4.5	Bluetooth	Transfers measurement results from caliper to cell controller.
Q	Caliper, wing skin, doubler, rib	Observable manufacturing element	ISO 23247-2:2021, 3.2	Aluminum and carbon fiber wing structural components and measurement device	Out of scope for digital twin framework.

C.3.3 Mapping of wing skin, doubler, and rib digital twins to digital twin entity

Implementation of the wing skin, doubler, and rib digital twins mapping to the digital twin entity is shown in Figure C.3 and Table C.3.



Key

operation and management sub-entity

application and service sub-entity

resource access and interchange sub-entity

Figure C.3 — Implementation mapping of wing skin, doubler, and rib digital twins to digital twin entity

Table C.3 — Mapping of wing skin, doubler, and rib digital twins to functional entity

Role in digital twin entity	Functional entity	ISO 23247-2 reference	Data type	Comment
Twin initializer interface	User interface FE	ISO 23247-2:2021, 6.4	AP242	Interface to user interface FE for retrieval of the initial/planned states of the digital twins involved.
Reporting interface	Reporting FE	ISO 23247-2:2021, 6.3.2.3	AP242	Interface to user interface FE for the as-measured condition of a wing skin, doubler, and rib.
Digital twin interface	Peer interface FE	ISO 23247-2:2021, 6.3.3.4	AP242	Links wing skin, doubler, rib, and wing assembly digital twins.
Viewer	Presentation FE	ISO 23247-2:2021, 6.3.1.2	AP242, Modern OpenGL	Displays wing skin, doubler, and rib as-measured condition
Digital twin manager	Maintenance FE	ISO 23247-2:2021, 6.3.1.4	AP242	Manages updating and sharing of digital twin representation
Digital twin representation	Digital representation FE	ISO 23247-2:2021, 6.3.1.3	AP242	Contains the digital model of the wing skin, doubler, and rib.

Table C.3 *(continued)*

Role in digital twin entity	Functional entity	ISO 23247-2 reference	Data type	Comment
Thickness updater	Synchronization FE	ISO 23247-2:2021, 6.3.1.1	QIF	Updates the as-measured wing skin, doubler, and rib condition as locations are measured.

C.3.4 Mapping of wing assembly digital twin to digital twin entity

Implementation of wing assembly digital twin mapping to the digital twin entity is shown in Figure C.4 and Table C.4.

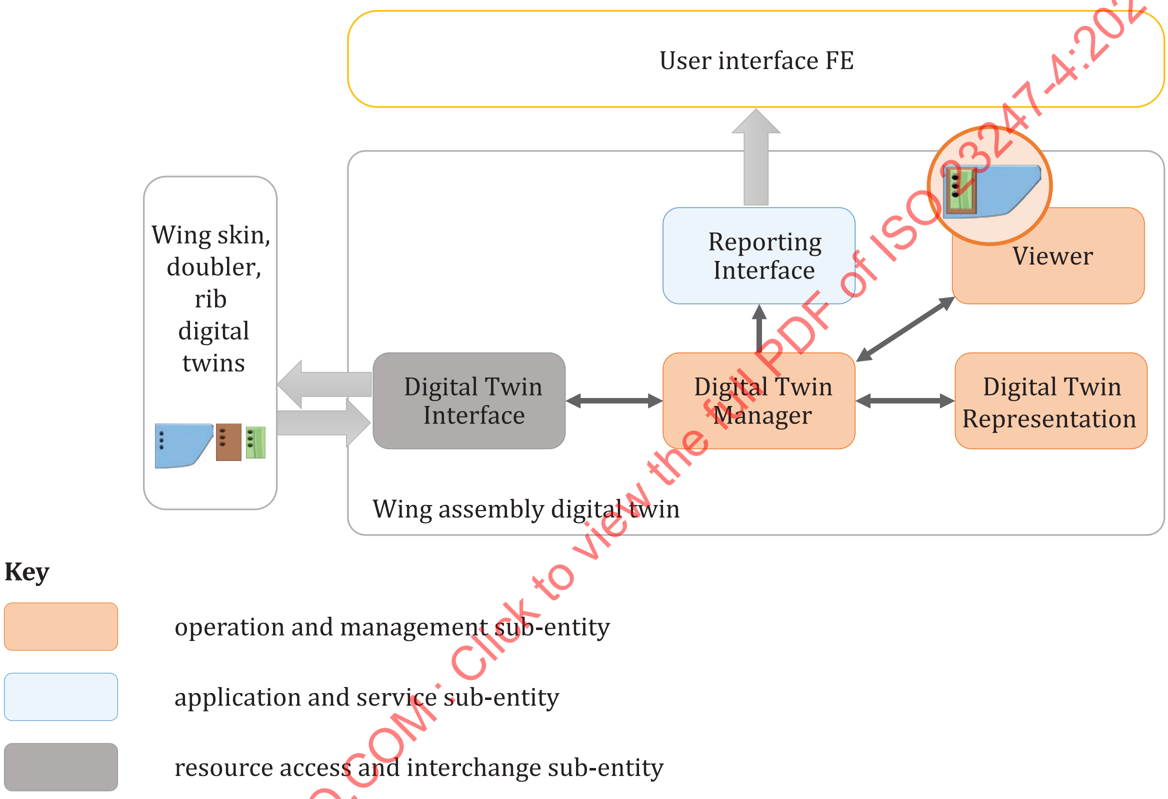


Figure C.4 — Implementation mapping of wing assembly digital twin to digital twin entity

Table C.4 — Mapping of wing assembly digital twin to functional entity

Role in digital twin entity	Functional entity	ISO 23247-2 reference	Data type	Comment
Reporting interface	Reporting FE	ISO 23247-2:2021, 6.3.2.3	AP242	Interface to user interface FE for the as-measured, virtually assembled condition of a wing assembly.
Digital twin interface	Peer interface FE	ISO 23247-2:2021, 6.3.3.4	AP242	Links wing assembly and wing skin, doubler, and rib digital twins.
Viewer	Presentation FE	ISO 23247-2:2021, 6.3.1.2	AP242	Displays wing assembly as-measured, virtually assembled condition.
Digital twin manager	Maintenance FE	ISO 23247-2:2021, 6.3.1.4	AP242	Manages updating and sharing of digital twin representation.

Table C.4 *(continued)*

Role in digital twin entity	Functional entity	ISO 23247-2 reference	Data type	Comment
Digital twin representation	Digital representation FE	ISO 23247-2:2021, 6.3.1.3	AP242	Contains the digital model of the wing assembly, based on the virtually assembled wing skin, doubler, and rib digital twins.

Annex D
(informative)

Optimization of material removal operations use case

D.1 Overview

Table D.1 describes the example using a template developed by ISO and IEC.

Table D.1 — Summary of the example on optimization of material removal operations

ID	Case number 3
Use case name	Optimization of material removal operations
Application field	Smart manufacturing.
Life cycle stage(s)/ phase(s) coverage	Production
Status	In-operation
Scope	Provide feedback loop between executed process and planned process
Initial (Problem) Situation	Inefficient communication of machining results to other systems in the enterprise Results are currently communicated manually and/or in a non-standardized way.
Objective(s)	Modelling digital twins of the product, process, and equipment enriches the data stream from process execution with context information about the process plan defined, cutting tools used, and the part being machined and measured.
Short description (not more than 150 words)	In a business case when material removal is provided as a service, it is important that performance data is made available and the service provider is given the opportunity to participate in the optimization-loop of the process. 1) log process performance throughout the life time of a cutting tool; 2) share performance log with service provider; 3) receive optimized process plan including cutting tool selection and performance parameters from service provider.
Stakeholders	Manufacturing shop floor personnel, compliance authorities (FAA, EASA, etc.), cutting tool vendors
Key technologies	CNC, metal cutting, geometric measurement
Relevant standards	AP238 and AP242 to describe digital twins of the process and product ISO 13399 to describe digital twins of the tooling ISO 23952 (QIF) to describe measurement results AP239 to keep relation between the states of the physical instances of the parts being produced, the process actually being performed and the equipment used (cutting tool and machine tool) MTConnect to communicate process state and measurement information to build digital twins ISO 6983 (G-Codes and M-Codes) is a conventional way of defining the actions of CNC technology
Standardization needs	ISO 23247 digital twin framework for manufacturing to describe how the standards inter-operate on the shop floor and between off-site support functions

Table D.1 *(continued)*

Remaining issues and future works	Adoption of the standards by the tooling suppliers and part manufacturers. It would be advantageous for both parties to participate in ISO 13399 projects aimed at enhancing the communication of cutting tool data to ensure seamless plug and play on the shop floor.

D.2 Operational sequences

D.2.1 Process flow

Figure D.1 shows the process flow of the optimization of material removal operations.

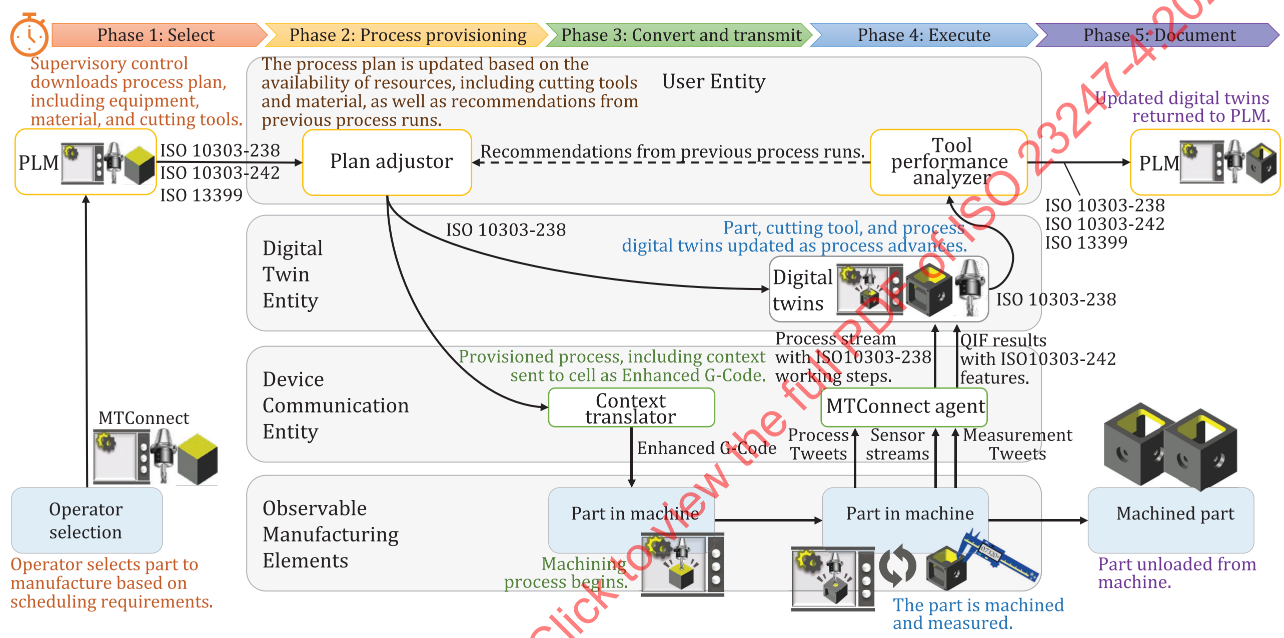


Figure D.1 — Process flow of material removal operations

D.2.2 Phase 1: Select

— Step 1: The operator selects a part to be manufactured based on scheduling requirements.

— Step 2: The Supervisory control downloads the process plan from PLM, which includes equipment, operator, material, setup requirements and cutting tools.

D.2.3 Phase 2: Process provisioning

— Step 1: The process plan is updated based on recommendations developed during previous production runs for this part.

— Step 2: The updated resource requirements, including optimal tool and material assignments are compiled for all process requirements.

— Step 3: The updated process plan is used to provision the digital twins for the machine, part, and cutting tools.

D.2.4 Phase 3: Convert and transmit

— Step 1: The Context translator extracts relevant context (e.g., workplan, working steps, process to toleranced feature mapping, and unique identifiers of cutting tool assignments and part being machined). The context translator then inserts the relevant context into a standardized implementation of the machine's native programming language (enhanced G-codes).

— Step 2: The enhanced G-codes are transmitted to the machine.

— Step 3: Machining is initiated.

D.2.5 Phase 4: Execution

— Three separate streams of context-rich data are output:

  — **Process:** As the part is being machined, significant execution step completions are transmitted to the MTConnect agent using tweets. These tweets include time stamps, and typically would occur at the beginning and completion of workingsteps and workplans. This information allows the process state to be known at any given time.

  — **Sensors**: During machining, various process, physical, electrical, and environmental characteristics are sensed and transmitted as time-stamped data to the MTConnect agent. These characteristics can include changes in the spindle or feedrate override. They can include coolant temperature, as well as spindle load and vibration.

  — **Measurement:** Physical part characteristics may be measured manually (by the operator) or by the machine at various stages of the production process. This measurement information is transmitted to the MTConnect agent via tweets.

— The three streams of data are synchronized by use of time stamps to update the digital twins of the machine, part, and cutting tools.

— A tool performance analyser utilizes information acquired from the machine, part, and cutting tool digital twins to generate recommendations for changes to future process runs.

D.2.6 Phase 5: Document

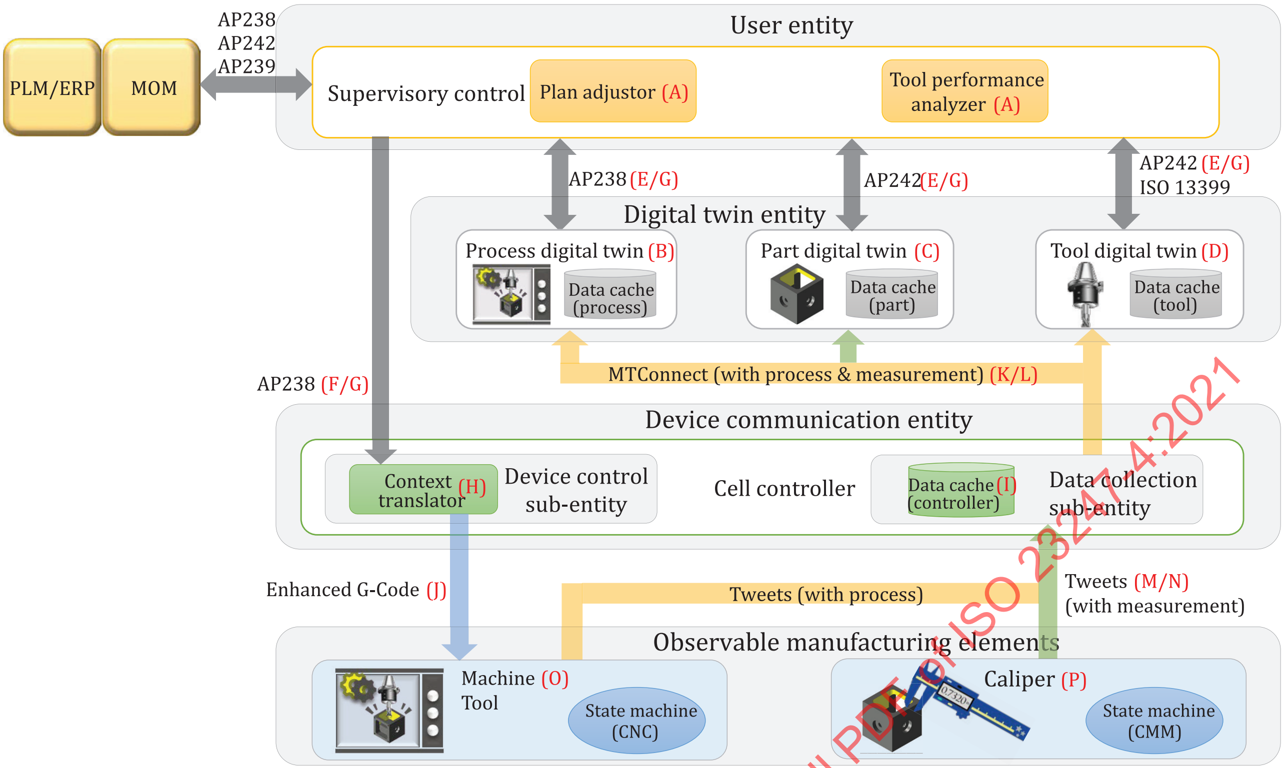
— The updated digital twins of the machine, part, and cutting tools are uploaded back to the PLM.

— The part is unloaded from the machine.

D.3 Mapping to the framework

D.3.1 Overview

Figure D.2 shows how the example may be implemented according to the framework.



Key

Models

product/process

State Stream

plunge complete, etc.

Measurements

hole dimensions, etc.

Instructions

G-codes, etc.

Figure D.2 — Material removal optimization

D.3.2 Implementation using framework

Implementation of material removal optimization use case with to the framework is in Table D.2 with tags shown in Figure D.2.

Table D.2 — Implementation of material removal optimization use case using framework

Tag	Role in use case	ISO 23247 name	ISO 23247 reference	Implementation technology	Comment
A	Supervisory control	User entity	ISO 23247-2:2021, 5.3.4	Windows executable using STEP modules	Provides interface to PLM through MOM. Compiles the process details based on the availability of resources and recommendations from previous process runs. Makes planned process available to digital twin and device communication entity.
B	Process digital twin	Digital twin entity	ISO 23247-2:2021, 5.3.3	Windows executable using STEP modules	Synchronizes process digital twin with OME using state stream from machine tool. Detects deviations from planned process. Presents process deviations in context of part design features and cutting tools during execution.
C	Part digital twin	Digital twin entity	ISO 23247-2:2021, 5.3.3	Windows executable using STEP modules	Synchronizes part digital twin with OME using state stream from machine tool and caliper. Simulates the material removal within a working step. Presents part digital twin in AP242 during execution.
D	Tool digital twin	Digital twin entity	ISO 23247-2:2021, 5.3.3	Windows executable using STEP modules	Synchronizes tool digital twin with OME using state stream from machine tool. Presents accumulated time-in-cut for tool digital twin at the end of execution.
E	Models communications (1)	User network	4.2	intranet	Provisions and retrieves process, part and tool digital twins when manufacturing is complete.
F	Models communications (2)	Access network	4.3	intranet	Sends adjusted manufacturing process to context translator.
G	Exchange model (of OMEs)	Digital twin representations	ISO 23247-3:2021, Clause 5	AP238, AP242, ISO13399	The appropriate models are used for the exchange of the state of process, part, and tool.
H	Context translator (for OMEs)	Data translation FE	ISO 23247-2:2021, 6.5.3	Windows executable using STEP modules	Converts AP238 into G-code using enhanced G-code conventions where context of process, part, and tool is included. In this use case, the data translator FE is a cross-system entity implemented in the device control sub-entity. See E.2 for details.

Table D.2 *(continued)*

Tag	Role in use case	ISO 23247 name	ISO 23247 reference	Implementation technology	Comment
I	Data cache (from OMEs)	Data pre-processing FE	ISO 23247-2:2021, 6.2.1.2	MTConnect agent	Caches state streams from machine tool and caliper to assure reliable updates of process, part, and tool digital twins.
J	Instructions communications	Proximity network	4.5	Industrial ethernet Enhanced G-codes	Transfers enhanced G-code commands from context translator to the machine tool.
K	State stream communications (1)	Access network	4.4	MTConnect	Transfers timestamped state streams from machine tool and caliper to digital twins.
L	State stream (1)	Requirements for information exchange in access network	Clause 7	MTConnect	Machine tool state stream, including process, parts and tool states. Caliper state stream, including part measurements.
M	State stream communications (2)	Proximity Network	4.5	OPC-UA	Transfers the raw state streams from machine tool and caliper to the data pre-processing FE.
N	State stream (2)	Requirements for information exchange in proximity network	Clause 8	OPC-UA	Machine tool state stream, including the processed enhanced G-code context statements inserted by the context translator (H). Caliper state stream, including measurement result and part feature measured.
O	Machine tool	Observable manufacturing element	ISO 23247-2:2021, 3.2	CNC controlled milling machine	Out of scope for digital twin framework
P	Caliper	Observable manufacturing element	ISO 23247-2:2021, 3.2	Caliper	Out of scope for digital twin framework

D.3.3 Mapping of process digital twin to digital twin entity

Implementation of process digital twin mapping to the digital twin entity is shown in Figure D.3 and Table D.3.