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Description

This is a draft for review of the CD for ISO 23247-6 Digital Twin Composition. On August 14 there will be a meeting of WG15 to confirm that the document is ready to begin its CD ballot. When that ballot begins each member country will have an opportunity to make comments on the document. The comments will be used to improve the Draft International Standard which will be produced after the CD ballot and industry testing.

ISO/CD 23247-6

ISO/TC 184/SC 4

Date: 2024-08-DD

Automation systems and integration — Digital twin framework for manufacturing — Part 6: Digital twin composition

CD stage

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Contents

Foreword

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This document was prepared by Technical Committee *[or Project Committee]* ISO/TC 184, *Automation systems and integration*, Subcommittee SC 4, *Industrial data*.

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

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Introduction

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 monitoring and 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 operations and business cooperation.

The type of manufacturing supported by implementing 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;
- ISO 23247-5: Requirements and guidance to use digital threads for connecting manufacturing lifecycle data to digital twin;
- ISO 23247-6: Requirements and guidance for performing digital twin composition for communication, collaboration, and interoperation between digital twins in manufacturing.

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

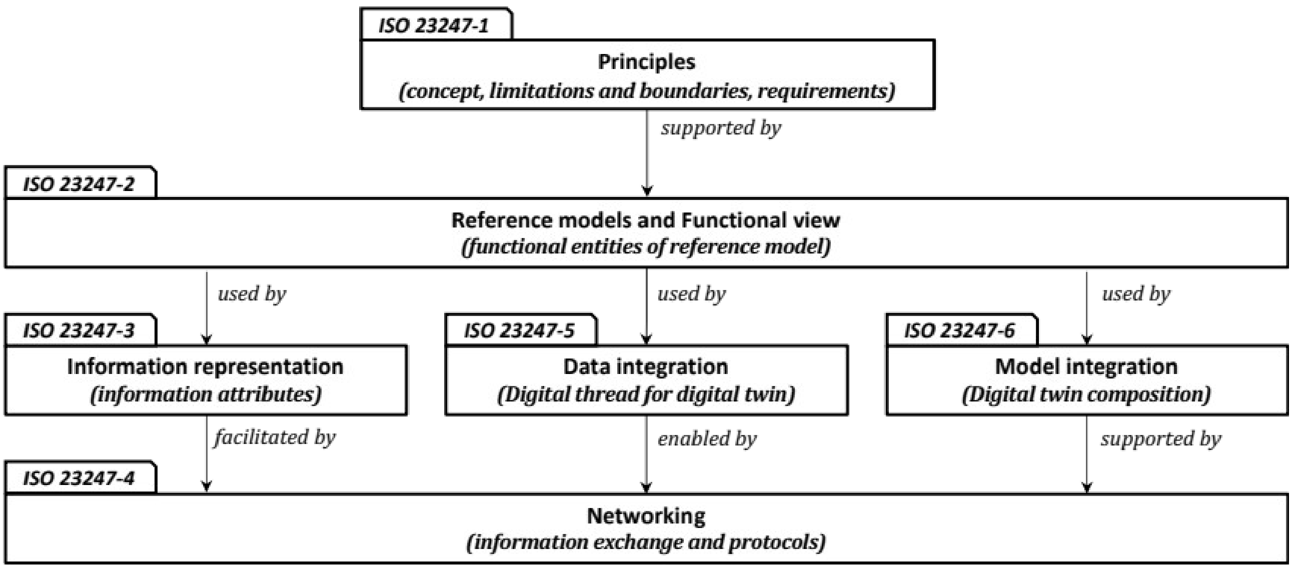


Figure 1 — ISO 23247 structure

This part proposes to address the digital twin composition needs in manufacturing by defining principles, describing methodologies, and providing use-case examples, so that digital twins can be configured for communication, aggregation, and interoperation throughout the product lifecycle. With digital twin composition, individual digital twins can collaborate together to enable reusability and scalability.

Manufacturing involves complex systems. One approach to managing a complex system is to create a large digital twin encompassing all related assets. However, it is impossible to build a single gigantic digital twin that includes all the requirements for a factory floor or a supply chain. Multiple digital twins for complex system elements will need to work together. In addition, manufacturers oftentimes receive digital twins from various vendors and third parties, and the composition of these digital twins is inevitable. Therefore, depending on the specific purpose and scenario, there are different kinds of digital twin compositions.

This part of the standard identifies classifications of various digital twin composition cases and develop requirements and implementation procedures for combining these digital twins. It offers a structured approach to integrating multiple digital twins, enabling manufacturers to manage complex systems with enhanced scalability and flexibility. By employing standardized protocols and methodologies for digital twin composition, manufacturers can ensure seamless interoperability between digital twins from various parties (vendors, solution providers, in-house developers). One significant achievement of digital twin composition is the reusability of digital twins, which helps reduce efforts and costs by allowing individual digital twins to be used for multiple times and purposes rather than created from scratch.

This document provides comprehensive requirements and procedures for integrated, unified, and federated approaches to digital twin composition. It includes step-by-step implementation guidelines and real-world use cases demonstrating the practical application of these guidelines. By following the analyses and guidelines in this document, manufacturers will be able to determine appropriate approaches to create scalable, flexible, and interoperable digital twin systems, effectively managing and analysing complex manufacturing processes and enhancing overall productivity and efficiency.

Automation systems and integration — Digital twin framework for manufacturing — Part 6: Digital twin composition

1 Scope

This part of ISO 23247 specifies digital twin composition in manufacturing by defining principles, describing methodologies, and providing use-case examples of digital twin communication, aggregation, and interoperation for manufacturing.

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 11354-1, *Requirements for establishing manufacturing enterprise process interoperability — Part 1: Framework for enterprise interoperability*

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, ISO 23247-2 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
digital twin composition
DTC

process of selecting(determining), connecting, and combining multiple digital twins

3.2
observable manufacturing element
OME

item that has an observable physical presence or operation in manufacturing

Note 1 to entry: Observable manufacturing elements include personnel, equipment, material, process, facility, environment, product, and supporting document.

[SOURCE: ISO 23247-1:2021(en), 3.2.5]

4 Overview and benefits of digital twin composition

4.1 Concept of digital twin composition

Digital twin composition (DTC) refers to the process of selecting, connecting, and combining digital twins to achieve complicated tasks through cooperation, as shown in Figure 2.

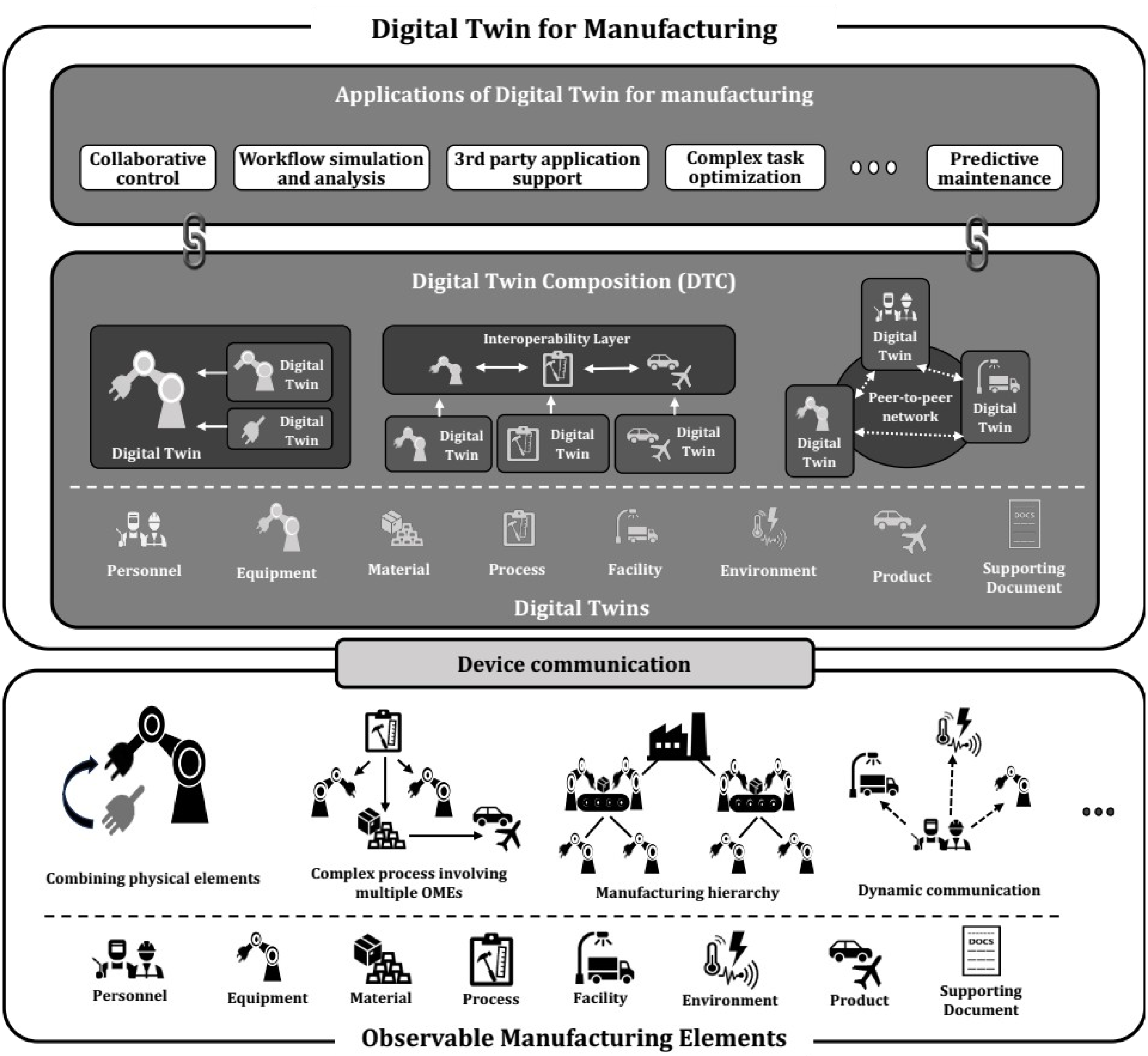


Figure 2 — Concept of digital twin composition

In manufacturing, there are thousands of OMEs, which may connect to each other in various ways depending on their purposes and characteristics. Digital twin composition (DTC) highlights different approaches to represent the interoperability of digital twins, reflecting the interoperability across physical elements. This interoperability could include combining physical elements into a single piece of equipment, managing complex processes involving multiple OMEs, establishing manufacturing hierarchies, and enabling dynamic communication through networks.

To increase operational efficiency and reusability of digital twins, DTC allows the integration of existing digital twins from the manufacturing floor or suppliers instead of designing and deploying digital twins from scratch. By facilitating real-time data exchange with interoperability approaches, DTC enhances the ability to monitor, simulate, and optimize manufacturing operations, ultimately improving efficiency, decision-making, and performance across the entire manufacturing lifecycle. DTC supports a range of applications such as collaborative control, sequence workflow analysis, third-party application support, complex task optimization, and predictive maintenance.

4.1.1 General

DTC enables individual digital twin models to cooperate for representing complicated tasks and achieving new goals. Reusing individual digital twins enhances flexibility, modularity, scalability, and efficiency in creating manufacturing digital twins.

4.1.2 Improving efficiency

Using DTC, a digital twin for complex systems can be efficiently and effectively generated to perform real-time monitoring and analysing the performance of a production line or the entire factory to determine how changes in one machine can improve the overall efficiency of production.

4.1.3 Increasing flexibility

DTC allows the composition of digital twins in a flexible way, making it easy to test and evaluate different scenarios and configurations, enabling them to optimize production and adapt to changing conditions on the shop floor.

4.1.4 Enhancing decision-making

DTC provides holistic, optimized decisions about production, maintenance, and manufacturing operations. The composition consists of multiple digital twins, each represents a different part of the system. It can be used to identify and analyse the synergies and interactions between different parts of the system.

4.1.5 Reusability

Digital twins are designed to be fit-for-purpose in a specific product lifecycle and application environment. Therefore, digital twins are often created from scratch, even for the same physical element in different applications or different manufacturing stages.

DTC reuses digital twin models without the constraints from their modelling languages, application platforms, running environments. It enhances interoperations between digital twins and avoid the duplicated efforts for digital twin development.

4.1.6 Reducing cost

DTC reduces time and costs for designing, developing, and operating digital twins by reusing the existing digital twins.

4.1.7 Fast deployment of digital twins

DTC enables rapid instantiations and interconnections of digital twins in manufacturing systems.

4.1.8 Flexibility and customization

DTC fosters the plug-and-play capabilities of digital twins to formulate a new digital twin through easier interfacing and configuration. These plug-and-play capabilities also facilitate customization of digital twins for specific use cases.

4.1.9 Scalability and extensibility

By utilising individual digital twins as building blocks to represent a complex physical manufacturing system, DTC can easily support scalability and extensibility.

DTC supports a wide range of manufacturing applications, from process monitoring and control to operational analytics and energy management. In addition, DTC also enables integration and adaptation across various processes and applications, including supply chains, which involve multiple partners and stakeholders.

4.1.10 Efficiency in trouble shooting

DTC helps troubleshoot complicated tasks of the manufacturing system by identifying problems and diagnosing causes. For example, performance degradation of a single machine affects the performance of the entire factory, a digital twin that helps fix the issue also help improve the overall efficiency of the production.

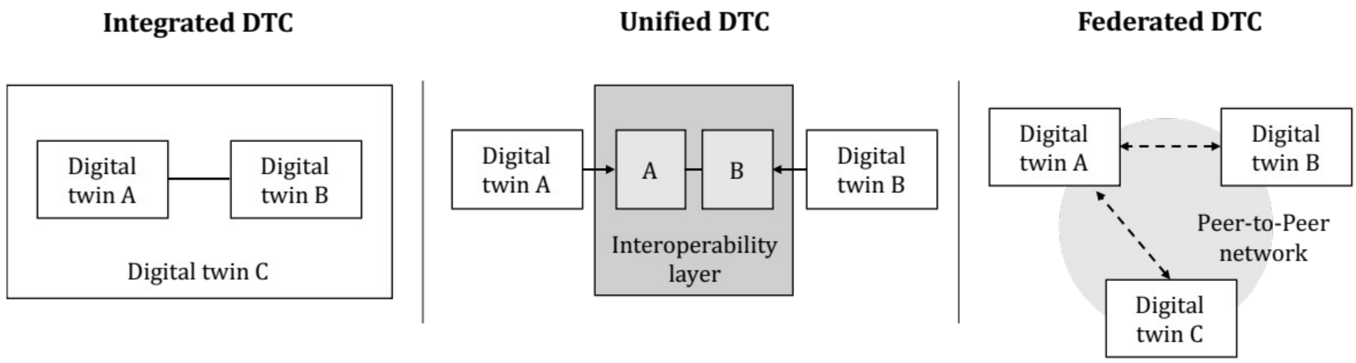
5 Classification of digital twin composition

5.1 General

DTC can be classified into three different types according to the interoperability approaches defined in ISO 11354-1. The classification of DTC is listed in below.

1. **Integrated DTC:** Digital twin composition supports the 'integrated' interoperability approach.
2. **Unified DTC:** Digital twin composition supports the 'unified' interoperability approach.
3. **Federated DTC:** Digital twin composition supports the 'federated' interoperability approach.

Figure 3 describes three types of DTC.



Key

Components

A	translated data of digital twin A
B	translated data of digital twin B

Connections and links

———	fixed connection within a common data format
——→	data exchanges with translation
←- - -→	dynamic connection over P2P network

Figure 3 — Types of digital twin composition

5.2 Integrated digital twin composition

An integrated DTC involves creating a single, comprehensive digital twin model that consolidates all data and functionalities from other individual digital twins into one overarching digital twin system. All digital twins conform to a common data schema and standardized protocols. It has a centralized control to govern the data and processes, ensuring consistency and uniformity. However, integrated DTC could become complex and less flexible as the number of sub-digital twins grows. An integrated DTC is ideal for cases where digital twins need centralized control or uniformity, such as a robot digital twin that is composed of a robot arm digital twin and a gripper digital twin.

Characteristics of an integrated DTC are listed below.

- **Interoperability design:**
  Through centralized control of data and processes
- **Representation format:**
  Uniform representation using common data schema and standardized protocols
- **Identification:**
  Local identifiers for sub-entities within the integrated digital twin
- **Independency:**
  Low independency because digital twins use the same data model and control logic, and are aligned with the same system, ensuring consistency and up-to-date status throughout the operation
- **Data exchanges:**
  Fully supportive because digital twins communicate through a common data model and information system, ensuring consistent and standardized data flow across all integrated components
- **Digital thread connection:**
  Digital thread ensures a seamless data flow and traceability of all entities through integrated digital twins.

5.3 Unified digital twin composition

A unified DTC involves connecting multiple digital twins while allowing them to maintain their individual models and schemas. Middleware, Application Programming Interfaces (APIs), or data integration platforms will be used for data exchange and interoperability between digital twins. It is more flexible than the integrated DTC, as each digital twin can maintain its specific characteristics and technologies. Interoperability can be achieved through the data mapping and translation layers. Complexity can be balanced by enabling diverse digital twins to communicate without forcing a single standard model. Unified DTC is ideal for cases where digital twins are developed independently but need to share data, such as equipment twins on a factory floor. For example, a process digital twin generated by compositing a product digital twin, a machine digital twin, tooling digital twins, and a material digital twin.

Characteristics of a unified DTC are listed below.

- **Interoperability design:**
  Data mapping and translation layers are used to facilitate interoperability.
- **Representation format:**
  A connectivity layer is used to map and translate between different formats of various digital twins.
- **Identification:**
  Shared identification services or protocols across digital twins need to be used. Identifiers should be unique between, at least across shared services or protocols.
- **Independency:**
  Independencies between digital twins are represented through shared interfaces and data models.
- **Data exchanges:**
  Efficient and compatible because digital twins operate on shared data models, which facilitate data exchange through connectivity layers that handle translations and mappings.
- **Digital thread connection:**
  Digital threads are linked through a connectivity layer that maps data flow across different digital twins.

5.4 Federated digital twin composition

In a federated DTC, digital twins interact directly with each other without a central coordinating entity. Each digital twin can request and provide services and data to other digital twins in the network. Because of no central control, each digital twin operates independently while communicating directly with other digital twins, allowing for dynamic and flexible interactions. Federated DTC could be very scalable, as new digital twins can join the network with minimal integration effort, but more preparation is needed. However, managing data consistency can be challenging due to the lack of central control. Ideally, this type of composition is suitable for decentralized cases where autonomy and direct interaction are important, such as IoT ecosystems with diverse and distributed devices.

Characteristics of a federated DTC are listed below.

— **Interoperability design:** Flexible interfaces and mutual adjustments are used to enable interoperability.
— **Representation format:** Independent formats are allowed, the DTC realizes digital twin connections through flexible interfaces.
— **Identification:** A global unique identifier for each digital twin enables the discovering and connecting other specified digital twins.
— **Independency:** Each digital twin operates on its unique data, models, and control logic, closely aligned with its specific system or application.
— **Data exchanges:** Data is exchanged peer-to-peer based on agreements through standard interfaces.
— **Digital thread connection:** Each digital twin can be linked to its own independent digital thread.

Table 1 summarizes aspects for each type of DTC.

Table 1 — Summary of digital twin composition types

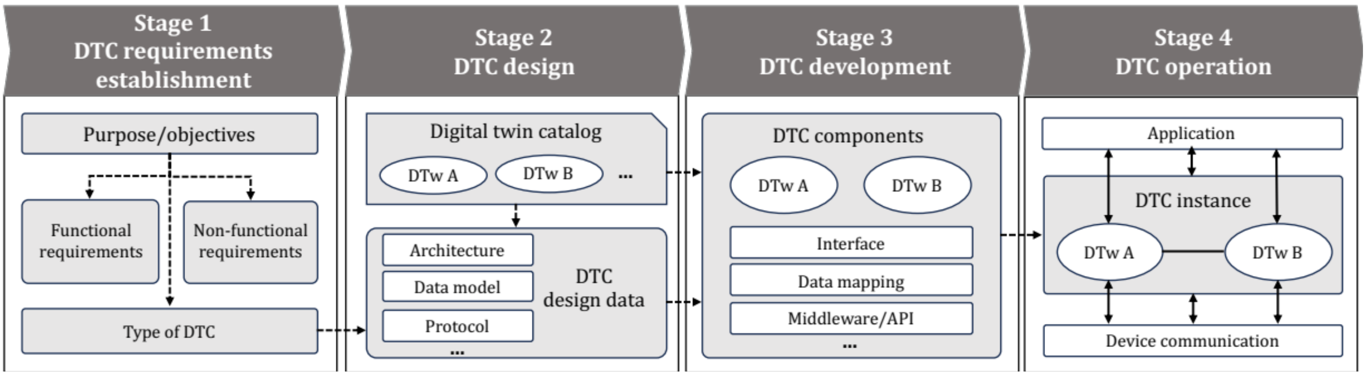
Aspects	Integrated DTC	Unified DTC	Federated DTC
Objectives	Creating a single, comprehensive digital twin by integrating individual digital twins	Connecting multiple digital twins while maintaining their individual models	Dynamically collaborating between independent digital twins without centralized coordination
Relations	Hierarchical and tightly coupled relationships; Representing assets that are physically combined	Loosely coupled but fixed relationship; Representing assets that are physically connected	Peer-to-peer relationships; Representing assets that are temporarily connected
Scalability	Limited, as adding more new elements requires significant reconfiguration	Moderate, allowing for the addition of new twins with minimal reconfiguration due to the use of middleware and APIs	High, with new digital twins quickly joining the network without significant changes to the existing systems
Flexibility	Low, due to rigid, centralized structure	Moderate, as each digital twin maintains its independence, allowing easier adaptation and integration	High, with decentralized interactions, accommodating new digital twins and changes without extensive reconfiguration
Reliability	High, due to centralized control and common protocols	Moderate, middleware manages interactions and failures across digital twins in a centralized manner	Low, depends on peer-to-peer interactions and network capabilities
Reusability	Limited, due to the highly integrated nature	Moderate, as individual digital twins can be reused in different compositions and contexts	High, allowing for flexible de-composition and use in various scenarios
Security	Centralized control ensures robust protection within the integrated system.	Middleware ensures data protection and access control across connected digital twins.	Decentralized security protocols focus on peer-to-peer encryption and access control to protect data integrity.
Complexity	High, due to the need of a centralized control system	Moderate, with middleware and standardized APIs handling	Low, in terms of central management but high, in

		most interactions	ensuring consistent peer-to-peer communications
Challenges	To design and maintain an integrated system	To ensure seamless interoperability through middleware configuration and integration	To ensure robust peer-to-peer communication and interactions
Examples	robot digital twin composed of robot arm and gripper digital twins	Equipment twins on a factory floor or a process digital twin composed with digital twins of product, machine, tools, and material Coordination in networked manufacturing where various manufacturing processes, systems, and entities are linked	Virtual enterprises and ad-hoc project teams Decentralized IoT ecosystems

6 Lifecycle of DTC

6.1 General

The lifecycle of a DTC is divided into four steps: DTC requirement establishment, DTC design, DTC development, and DTC operation, as shown in Figure 4.



Key

- - -→ operation flow

—— connection between digital twins

←→ Interface between entities

Figure 4 — The Lifecycle of digital twin composition

6.2 Lifecycle Stage 1: DTC requirements establishment

This stage defines the purpose and objectives of digital twin composition. The appropriate type of DTC is determined depending on specific requirements or constraints. This stage is divided into several sub-steps as below.

- Define purposes and objectives that are to be achieved with DTC.
- Establish functional requirements of DTC such as resulted DTC functionalities, data types and interfaces.
- Set up non-functional requirements of DTC. (e. g., performance criteria, Key Performance Indicators (KPIs), energy efficiencies)
- Select appropriate DTC type to achieve goals and meet requirements.

6.3 Lifecycle Stage 2: DTC design

This stage strategizes the composition of digital twins, informed by the requirements and selected DTC type in the previous step. This stage is divided into several sub-steps as below.

- Catalog the existing digital twins with their functionalities, data formats, technology, and interfaces.
- Generate DTC design data depending on the selected DTC type and functional requirements. DTC design data includes common data standards and formats, an architecture framework to support selected DTC types, and communication protocols to exchange data between digital twins.

6.4 Lifecycle Stage 3: DTC Development

This stage identifies and selects appropriate digital twins that align with the established DTC design step. This stage is divided into several sub-steps as below.

- Deploy digital twins that will be involved to DTC.
- Deploy middleware and APIs to support DTC.
- Establish data exchanges and data mappings.
- Create interfaces they need.
- Conduct testing and evaluation.

6.5 Lifecycle Stage 4: DTC Operation

This stage executes the implemented DTC in parallel with the corresponding manufacturing operation.

- Digital twin components such as data models, simulation algorithms, and user interfaces are integrated based on the previously defined plan.
- Components digital twins need to be connected, data streams between them need to configured, and the synchronization between virtual and physical systems need to be realized.
- Keep the DTC during manufacturing with continuously updates.
- Establish monitoring and maintenance process during DTC.

7 Requirements and development procedures of digital twin composition

7.1 Common requirements for all types of digital twin composition

Based on the fundamental principles of DTC, there are several common requirements belonging to all DTC types. Common requirements are listed below. Some of the requirements may be different in detail depending on the types of DTC.

— **REQ_COM_01:**
A catalog shall be deployed for all digital twins to indicate their functionalities, data models, technologies, and interfaces.
— **REQ _COM_02:**
Common data standards and formats shall be established to ensure compatibility and uniformity in data exchange between digital twins.
— **REQ _COM_03:**
Standardized communication protocols and APIs shall be implemented to facilitate data exchange and communication between digital twins.
— **REQ _COM_04:**
A scalable architecture shall be designed and developed to allow for the composition of additional digital twins without significant reconfiguration.
— **REQ _COM_05:**
Event-driven architectures or communication mechanisms shall be used to handle real-time data processing and updates ensuring the digital twin is always current.
— **REQ _COM_06**
Data synchronization mechanisms shall be used to ensure that updates in individual digital twins are reflected promptly in the system.
— **REQ _COM_07:**
Processes for supporting data consistency and quality across the digital twins shall be implemented.
— **REQ _COM_08:**
Authentication and authorization mechanisms shall be implemented to control access and ensure secure data exchanges.
— **REQ _COM_09:**
Data encryption shall be used to protect data, ensuring privacy and security.
— **REQ _COM_10:**
Data governance policies shall be established to manage data quality, ownership, and lifecycle.
— **REQ _COM_11:**
Maintenance procedures shall be established to monitor performance of digital twin systems and regularly update, improve, and optimize the system addressing any issues that arise.

7.2 Requirements and development procedures of integrated digital twin composition

Creating an integrated digital twin by compositing multiple individual component digital twins involves several requirements to ensure seamless integration, consistency, and functionality. Based on these generic requirements, each use case must have its own specific objectives and requirement.

— **REQ _INT_01:**
A common data model shall be developed for all component digital twins to adhere to, ensuring consistency in data formats, structures, and semantics.
— **REQ _INT_02:**
Standardized data ontologies shall be selected to define relationships and hierarchies within the data, ensuring common understanding across digital twins.
— **REQ _INT_03:**
Modular design approaches shall be taken to allow component digital twins to be updated or replaced without affecting the integrated system.
— **REQ _INT_04:**
Data mapping and transformation mechanisms shall be developed to translate data from individual digital twins into the integrated digital twin.
— **REQ _INT_05:**
A graphical user interface shall be developed to provide a comprehensive view of the integrated data and functionalities.

Implementation procedures or steps for developing an integrated DTC are shown in Figure 5. By following these steps, an integrated DTC can be implemented to consolidate the strengths and capabilities of multiple digital twins into a single, powerful digital twin that provides comprehensive, consistent, and real-time insights and functionalities. Depending on the specific purpose and requirements, some use cases may not need all the steps (e.g., an integrated user interface may not be required)

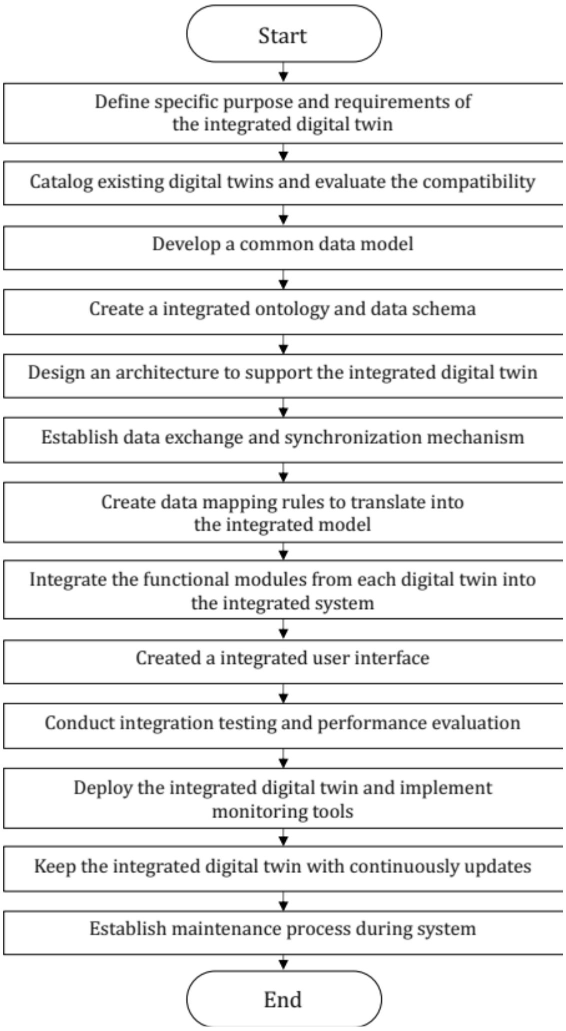


Figure 5 — Development procedures of integrated digital twin composition

7.3 Requirements and development procedures of unified digital twin composition

Creating a unified digital twin involves several key requirements to ensure seamless integration, interoperability, and functionality. These requirements are critical for combining data and functionalities from different digital twins into a cohesive, unified system. Here are the primary requirements.

- **REQ _UNI_01:**
  Mechanisms for data mapping and transformation shall be identified or developed to translate data from individual digital twins into a unified format.
- **REQ _UNI_02:**
  Middleware solutions shall be used to implement an interoperability layer that facilitates data integration and communication between different digital twins.
- **REQ _UNI_03:**
  APIs and connectors shall be developed and used to enable interoperability between digital twins and interoperability layer.
- **REQ _UNI_04:**
  A modular design approach shall be taken to enable individual digital twins to be updated or replaced with minimum impact to the entire system.
- **REQ _UNI_05:**
  Data synchronization mechanisms shall be implemented to ensure that updates in individual digital twins are promptly reflected across the unified system.
- **REQ _UNI_06:**
  The user interface shall be intuitive and user-friendly, providing easy access to the combined capabilities of the digital twins.
- **REQ _UNI_07:**
  The performance of the unified digital twin shall be continuously optimized to handle large volumes of data and real-time processing demands efficiently.

Implementation procedures for developing a unified DTC are shown in Figure 6. Unifying multiple digital twins involves a structured approach to ensure interoperability, consistency, and efficient data exchange among different digital twins. By following these steps, a unified digital twin system can be developed by leveraging combined capabilities of individual digital twins for enhanced operational efficiency and decision-making. Depending on the specific purpose and requirements, some use cases may not need all the steps.

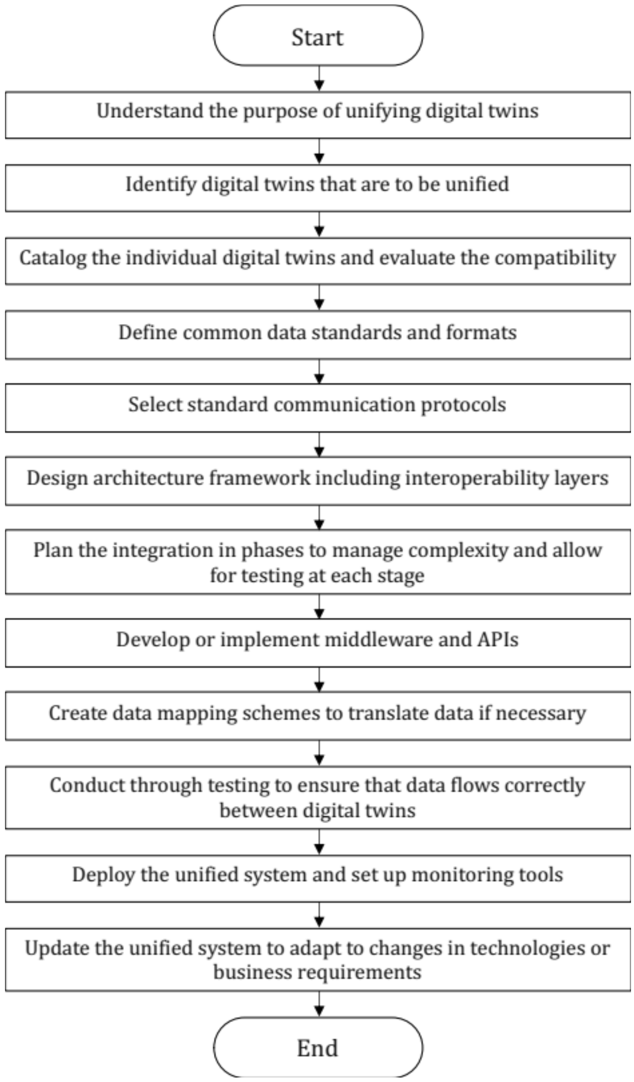


Figure 6 — Development procedures of unified digital twin composition

7.4 Requirements and development procedures of federated digital twin composition

Creating a federated DTC involves several key requirements to ensure seamless integration, interoperability, and functionality. These requirements are critical for combining data and functionalities from different digital twins into a cohesive, collaborated system. Here are some primary requirements:

- **REQ _FED_01:**
  Standard communication frameworks or protocols for peer-to-peer messaging shall be used.
- **REQ _FED_02:**
  A decentralized network topology shall be designed and developed to allow digital twins to communicate directly with each other without a central coordinating entity.
- **REQ _FED_03:**
  Peer discovery mechanisms shall be implemented for individual digital twins to dynamically discover each other.
- **REQ _FED_04:**
  Data consistency strategies shall be implemented to manage data consistency across the peer-to-peer (P2P) network.
- **REQ _FED_05:**
  Flexible interaction models shall be used to allow digital twins dynamically form and dissolve connections based on needs and conditions.
- **REQ _FED_06:**
  The network and communication protocols shall be optimized to minimize latency and ensure real-time or near-real-time interactions between digital twins.
- **REQ _FED_07:**
  The network shall be resilient to failures, ensuring that the failure of one or more peers does not disrupt the entire federated system.
- **REQ _FED_08:**
  Fault tolerance mechanisms (e.g., redundancy, failover, and load balancing) shall be implemented to enhance network reliability.
- **REQ _FED_09:**
  Distributed data storage solutions shall be used to store and manage data across the network, ensuring availability and redundancy.
- **REQ _FED_10:**
  Data sharing policies shall be defined for data sharing and access control to manage how data is shared between digital twins.

Implementation procedures for developing a federated DTC are shown in Figure 7. A federated DTC involves a decentralized approach where each digital twin interacts directly with others without a central coordinating entity. By following these steps, A P2P integration of multiple digital twins can be realized by leveraging their combined capabilities in a decentralized and autonomous manner. Depending on the specific purpose and requirements, some use cases may not need all the steps.

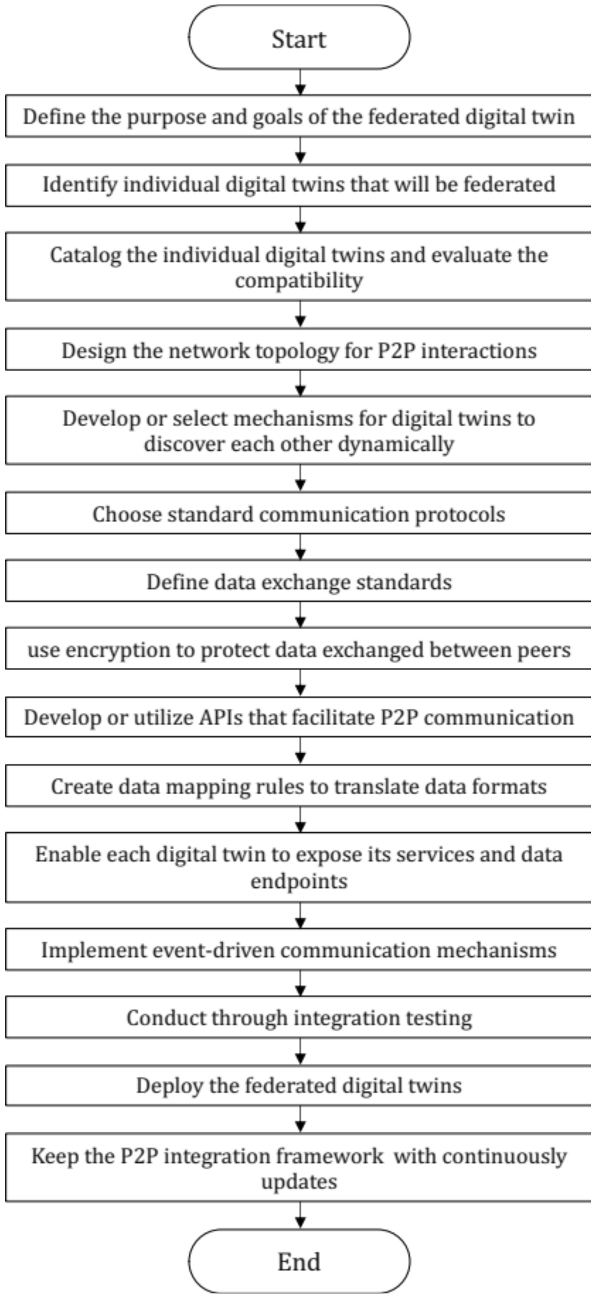


Figure 7 — Development procedures of federated digital twin composition

8 Mapping requirements to the digital twin reference architecture

8.1 General

As shown in Figure 1, this document is related to ISO 23247-2 digital twin reference architecture in the aspect of using functionalities of digital twin reference architecture. This clause provides the mapping of DTC requirements to relevant functionalities of the digital twin framework architecture.

Table 2 summarizes the mappings of DTC requirements to relevant functionalities. Functional entities with check marks indicate that they should provide enhancements to meet DTC requirements. However, this does not mean that functional entities without mark lack support or relevance for DTC. The related sub-clauses are also indicated with marks.

Table 2 — Summary of mapping DTC requirements to relevant functionalities

Functional entity (FE)		Common requirements	Integrated DTC requirements	Unified DTC requirements	Federated DTC requirements
Data collection Sub-entity	Data collecting FE	-	-	-	-
	Data pre-processing FE	-	-	-	-
	Collection identification FE	-	-	-	-
Device control Sub-entity	Controlling FE	-	-	-	-
	Actuation FE	-	-	-	-
	Control identification FE	-	-	-	-
Operation and management Sub-entity	Digital representation FE	✓ **(8.2.1)**	✓ **(8.3.1)**	-	-
	Presentation FE	✓ **(8.2.2)**	✓ **(8.3.2)**	-	-
	Synchronization FE	✓ **(8.2.3)**	-	✓ **(8.3.1)**	-
	Maintenance FE	✓ **(8.2.4)**	-	✓ **(8.4.2)**	-
Application and service Sub-entity	Simulation FE	-	-	-	-
	Analytic service FE	-	-	-	-
	Reporting FE	-	-	-	-
	Application support FE	-	-	-	-
Resource access and interchange Sub-entity	Interoperability support FE	✓ **(8.2.5)**	-	✓ **(8.4.3)**	✓ **(8.5.1)**
	Plug & play support FE	-	✓ **(8.3.3)**	✓ **(8.4.4)**	✓ **(8.5.2)**
	Peer interface FE	✓ **(8.2.6)**	-	-	✓ **(8.5.3)**
	Access control FE	✓ **(8.2.7)**	-	-	-
User entity	User Interface FE	-	✓ **(8.3.4)**	✓ **(8.4.5)**	-
Cross-system entity	Data translation FE	-	✓ **(8.3.5)**	✓ **(8.4.6)**	✓ **(8.5.4)**
	Data assurance FE	✓ **(8.2.8)**	-	-	✓ **(8.5.5)**
	Security support FE	✓ **(8.2.9)**	-	-	✓ **(8.5.6)**

8.2 Mapping requirements for all types of digital twin composition

8.2.1 Digital representation FE

— **From REQ_COM_01:**
The digital representation FE provides catalogs of all existing digital twins to indicate their characteristics such as functionalities, data models, technologies and interfaces.

8.2.2 Presentation FE:

— **From REQ_COM_02:**
The presentation FE establishes common data standards and formats for component digital twins to exchange data between digital twins.

8.2.3 Synchronization FE:

— **From REQ_COM_05 and REQ_COM_06:**
The synchronization FE provides synchronization between digital twins, ensuring all digital twins in the system are always current by reflecting related status promptly.

8.2.4 Maintenance FE:

— **From REQ_COM_11:**
The maintenance FE uses monitoring tools that especially focus on operational monitoring between digital twins to update, improve and optimize between digital twins addressing issues that arise.

8.2.5 Interoperability support FE:

— **From REQ_COM_04:**
The interoperability support FE ensures to provide scalable architecture to allow for joining digital twins to the composited system without significant reconfigurations.

8.2.6 Peer interface FE:

— **From REQ_COM_03:**
The peer interface FE provides interface between digital twins by using standardized communication protocols and APIs.
NOTE As standard communication protocols, it could be used MQTT, HTTP, REST, OPC-UA, etc.

8.2.7 Access control FE:

— **From REQ_COM_08:**
The access control FE controls access of digital twin from other digital twins and secure data exchanges between digital twins.

8.2.8 Data assurance FE:

— **From REQ_COM_07 and REQ_COM_10:**
The data assurance FE ensures data consistency and quality across digital twins, and establishes data governance policies for managing data ownership and lifecycle.

8.2.9 Security support FE:

— **From REQ_COM_09:**
The security support FE uses data encryption to protect data, ensuring privacy and security.

Mapping requirements for integrated digital twin composition

8.2.10 Interoperability support FE

- **From REQ_UNI_02 and REQ_UNI_03:**
  The interoperability support FE uses middleware solution to implement interoperability layer including APIs and connectors.

8.2.11 Plug and play support FE

- **From REQ_UNI_04:**
  The plug and play support FE enables modular design to allow individual digital twins to be updated or replaced without affecting the unified system including interoperability layer.

8.2.12 User interface FE

- **From REQ_UNI_06:**
  The user interface FE interfaces to interoperability layer, providing easy access to the combined capabilities of the digital twins.

8.2.13 Data translation FE

- **From REQ_UNI_01:**
  The data translation FE implements mechanisms in the interoperability layer that translates data from individual digital twins into common format available in a unified system.

8.3 Mapping requirements for federated digital twin composition

8.3.1 Interoperability support FE

- **From REQ_FED_02:**
  The interoperability support FE enables to develop a decentralized network for federated system that allows direct communication between digital twins without central coordination.

8.3.2 Plug and play support FE

- **From REQ_FED_03:**
  The plug and play support FE uses peer discovery mechanisms to allow digital twins to dynamically discover each other.
  NOTE peer discovery mechanisms could be implemented using decentralized directories, DHTs (Distributed Hash Tables), or gossip protocols.
- **From REQ_FED_05:**
  The plug and play support FE enables flexible interactions that allows digital twins dynamically form and dissolve connections within the federated system.

8.3.3 Peer interface FE

- **From REQ_FED_01:**
  The peer interface FE provides peer-to-peer messaging with standardized communication protocols and framework.
  NOTE peer-to-peer messaging protocol could be MQTT or WebSockets.
- **From REQ_FED_06 and REQ_FED_06:**
  The peer interface FE ensures minimized latency for real-time or near-real-time interactions, fault tolerance for reliabilities in communication between digital twins.

8.3.4 Data translation FE

- **From REQ_FED_10:**
  The data translation FE implements data sharing policies between digital twins.

8.3.5 Data assurance FE:

- **From REQ_FED_04:**
  The data assurance FE uses network consistency mechanisms for peer-to-peer network in federated system where data is exchanged between digital twins.
  NOTE Data consistency strategies for peer-to-peer network could be consensus algorithms or conflict resolution mechanisms.
- **From REQ_FED_09:**
  The data assurance FE uses distributed data storage solutions to manage data across the network, ensuring availability and redundancy.

8.3.6 Security support FE:

- **From REQ_UNI_07:**
  The security support FE ensures resiliency of the federated system that failure of one or more peers does not disrupt the entire system.

9 Summary

This document describes digital twin composition for manufacturing, enabling interoperability between digital twins to manage complex tasks. Depending on the target digital twins or systems, an appropriate type of DTC—integrated, unified, or federated—can be selected. This document provides guidance on requirements and deployment procedures for each DTC type. Aligning these requirements with the ISO 23247 digital twin framework clarifies the necessary functionalities. Practical use cases for each DTC type are detailed in the Annex.

Annex A
(informative)

Unified digital twin composition use case — Robot arm with gripper

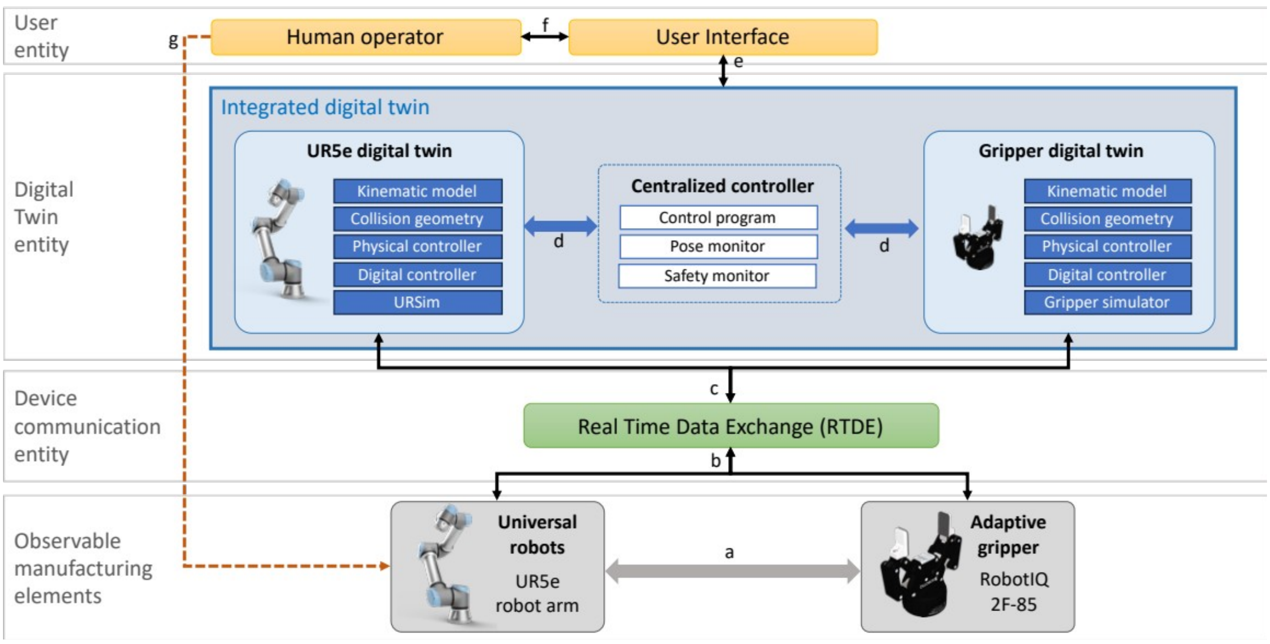
A.1 Overview

Use case name	Robot arm and gripper digital twin composition
Scope	Composition of two individual digital twins (i.e., a robot arm digital twin and a gripper digital twin) from different sources to enable core functionalities of an integrated robot digital twin system. The composition allows for the gripper component to be swapped for a different type easily. This integrated digital twin could then be used in any manufacturing environment to achieve various objectives. The use case follows requirements and procedures in this part of the standard and demonstrates the feasibility, usefulness, and efficiency of the guideline.
Initial (Problem) situation	Robot arms or grippers on their own have limited capabilities, so they need to be combined to manipulate surrounding objects and achieve practical goals. A digital twin that simulates the whole robot arm and gripper system as a single entity must be developed. However, individual digital twins for robot arms and grippers are often developed by different vendors, and they normally have high variability in their shapes and functions. Creating a single digital twin to represent both the robot arm and the gripper for every new configuration could be very costly and would result in duplicated efforts.
Objective(s)	To reduce the effort required to create a digital twin of the whole robot system, a composition of two existing digital twins, one for the robot arm and one for the gripper, would be more efficient and support reusability and scalability. For example, if each digital twin is developed by its hardware vendor, then the only required development effort will be interoperability between the two.
Composition type	Integrated DTC
Short description	We have two separate digital twins, one for the robot arm and one for the gripper, from the vendors or third parties. The use case demonstrates how they can be integrated together according to the guidelines discussed in this part of ISO 23247. The individual digital twins can operate independently. The robot arm twin can monitor the motion of the arm in space. The gripper twin can monitor the state of the gripper as it is controlled. A single, integrated digital twin is developed to combine the two individual twins. The integrated digital twin is responsible for controlling the robot arm because it knows the gripper's constraints for safe configurations of the robot arm. Therefore, it operates the robot arm in a safer manner. The integrated digital twin can be used to verify that the physical robot arm is correctly executing its motion, notify human operators, or issue a protective stop in the event there is a significant deviation, as well as potentially support predictive maintenance.
Stakeholders	Production managers, system integrators, robot arm vendors, gripper vendors, machine operators, maintenance personnel
Relevant standards	• ISO 23247 Digital Twin Framework for Manufacturing to support the

	development of individual and integrated digital twins. • Robot Operating System (ROS) as an industry standard for robotics applications. ROS is an open-source software development kit that provides a standardized platform for developers to use across industries. • Unified Robot Description Format (URDF), a standardized format used in ROS for describing and modelling robots. URDF is an XML specification that allows users to describe a robot's kinematic properties, visual representation, and collision model. • Transmission Control Protocol: TCP is a protocol for reliable communication between computers. • OMG Interface Definition Language (IDL), a descriptive language used to define data types and interfaces in a way that is independent of the programming language or operating system/processor platform • DDS: Secure message passing middleware for digital communication.
Standardization needs	It would benefit from specified data formats and protocols for interoperability between robot arms and grippers.

A.2 Operation sequences

A.2.1 Process flow



Key

a Modbus data stream between robot arm and gripper
b process data stream to device communication entity
c process data stream to digital twins
d data exchange using IDL data model built into ROS
e data exchange between digital twin and user entity
f notification of events to human operator
g offline control via human intervention

Figure A.1 — Robot arm and gripper digital twin composition

A.2.2 Phase 1: DTC requirements establishment

Because either a robot arm digital twin or a gripper digital twin will not perform tasks on its own, the two digital twins need to be combined and centrally controlled to manipulate surrounding objects and achieve practical goals. Therefore, it fits the integrated DTC scenario. The composition type will be Integrated Digital Twin Composition.

— A single, integrated digital twin is developed to combine the two individual twins to control the robot arm and the connected gripper for high-integrity, safe operation.
— The integrated digital twin simulates the operation of the physical robot arm with gripper and can be used to verify if it correctly executes its motion and supports predictive maintenance.
— The integrated digital twin calculates the positional and rotational error between the physical and digital end-effectors.
— The integrated digital twin warns the operator when the error exceeds a threshold.
— The integrated digital twin helps avoid collisions with known obstacles in surroundings.
— The integrated digital twin shall limit the error within 1 mm.

A.2.3 Phase 2: DTC design

— We have two separate digital twins: one for the robot arm using URSim that simulates UR5e, but not synchronizes with the robot arm; and one for the gripper (Robot IQ) developed.
— We follow the reference architecture in ISO 23247 -Part2 and ROS 2 as frameworks for extensibility and availability of vendor-provided digital twins.
— The OMG's Interface Definition Language (IDL) is used as the common data model because it is built into ROS.
— The Real-Time Data Exchange (RTDE) is used to communicate physical robot because it has a vendor-provided ROS interface.

A.2.4 Phase 3: DTC development

— URSim is used as the basis for the robot arm digital twin.
— A RTDE interface is used as the basis for the gripper digital twin.
— New data types are established in IDL.
— Middleware programs in ROS are developed to achieve the functional requirements.
— The integrated digital twin is tested to verify non-functional requirements. The DTC user interface is developed to support day-to-day operation.

A.2.5 Phase 4: DTC Operation

— Once it is developed, the integrated digital twin is able to simulate the robot arm with the gripper.
— The operation is monitored using data logged.
— The integrated digital twin can also verify that the physical robot arm is correctly executing its motion, notify human operators, or issue a protective stop in the event there is a significant deviation.

Annex B
(informative)

Unified digital twin composition use case — Cutting process

B.1 Overview

Use case name	Digital twin composition for enhancing cutting tool optimization
Scope	Provide composition of vendor-provided digital twins with the operator's process planning twin
Initial (Problem) situation	Currently, the operator designed and generated digital twins of cutting tools based on data from tool suppliers. The tool analyser is dependent of the application in which the operator uses. For optimizing tool life, cutting tool vendors have limitations in collecting information on cutting tools during their lifecycle
Objective(s)	To compose and connect digital twins of cutting tools supplied by vendors with operator-generated process plans, enriching the cutting process with advanced analytics and optimization capabilities to enable reusable and flexible changes of cutting tools.
Composition type	Unified DTC between process digital twin and cutting tool digital twin.
Short description	Leveraging vendor digital twins and operating them with operator process twins, aiming to enhance cutting processes with enriching service supported by cutting tool vendors 1) Use a meta-model for cutting tool digital twins to ensure the selection of the appropriate digital twin that fits the process twin 2) Enhanced process analytics and optimization supported by tool vendors 3) Improved real-time decision-making through shared tool performance data 4) Streamlined tool selection and optimization process using comprehensive digital twin inventory 5) Reusability of cutting tool digital twins for multiple processes or projects, without the need for re-creation from scratch
Stakeholders	Manufacturing operator, Cutting tool vendors
Relevant standards	AP238 and AP242 to describe digital twins of the process and the product ISO 13399 to describe the cutting tool data AP239 to keep the relations between the states of the physical instances of the parts being produced, the process being performed, and the equipment used (cutting tool and machine tool) MTConnect to communicate process states and measurement information from the equipment. ISO 6983 (G-Codes and M-Codes) to define the machining programs
Standardization needs	ISO 23247-6 digital twin composition to describe how to search, select, and integrate vendor-provided digital twins to be composed to a new process digital

	twin

B.2 Operation sequences

B.2.1 Process flow

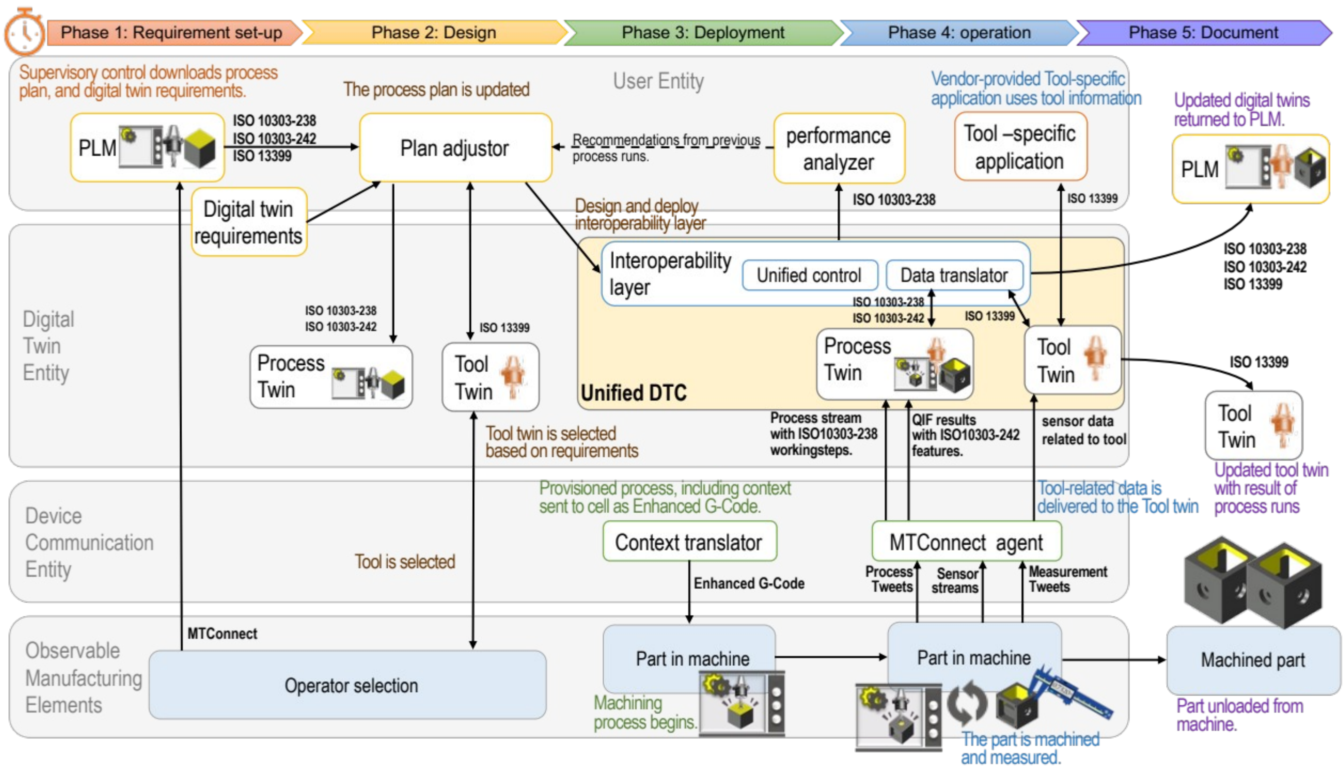


Figure B.1 — Cutting process and cutting tool digital twin composition

B.2.2 Phase 1: DTC requirements establishment

— The operator selects a part to be manufactured based on scheduling requirements.
— The supervisory control downloads the process plan from the PLM system, which describes equipment, operator, material, setup requirements, and cutting tools
— The supervisory control generates requirements for selecting tool digital twins, including both OME- and digital twin-specific requirements (i.e., supporting digital twin models, communication protocols, required properties, etc.)

B.2.3 Phase 2: DTC design

— From the digital twin inventory, supervisory control searches for an appropriate tool for digital twins. The meta-model of the digital twins is used to match the requirements and properties of a cutting tool digital twin.
— Connect the selected cutting tool digital twin to a process digital twin with an interface. In this example, AP242 is used to exchange the model data.
— The process plan is updated based on the recommendations developed during previous production runs for this part, and the tool status is stored in the cutting tool digital twin (simulation).
— The updated resource requirements, including the optimal tool (from the cutting tool digital twin) and material assignments, are compiled for the process requirements
— The updated process plan is used to provision the digital twin for the process, including the machine and the part, the digital twin for the cutting tool, and the connection between digital twins.

B.2.4 Phase 3: DTC deployment

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

B.2.5 Phase 4: DTC Operation

— Streams of data are synchronized by using timestamps to update the digital twins of the process and the cutting tools. A digital twin of the cutting tool can gather data only related to the tool's status and performance.
— A tool performance analyser utilizes information acquired from the cutting tool digital twins to generate recommendations for changes to future process runs. Performance analyser can be used with external software, since the digital twin of the cutting tool is not a dependent of application environment of the process digital twin.
— The digital twins of the process and the cutting tools are updated. The process digital twin is uploaded to PLM and the cutting tools digital twin is stored in the digital twin inventory for future use.
— The part is unloaded from the machine.

Annex C
(informative)

Unified digital twin composition use case — Refrigerator inner case

C.1 Overview

Use case name	Digital twin composition for the CRF process optimization and anomaly detection
Scope	Composition of digital twins for roll forming, U-bending, and unloading the machine into a high-level process digital twin to enhance anomaly detection and optimize the CRF process
Initial (Problem) situation	Currently, digital twins of each machining process are generated and operated in silo, leading to inefficiencies and difficulties to optimize schedules and undetected anomalies in the CRF process. Multiple digital twins of each process exist independently and are used separately based on the application, which is limited to cooperation between applications. Currently, there are no standardized approaches to composing data-driven digital twin models.
Objective(s)	To create a high-level digital twin that connects the digital twins of individual machines, allowing for simulating sequential schedules and collecting data from each machining process to be used in data-driven optimization models. To adopt a system-of-systems approach that collects independent digital twin systems to work together to achieve common goals.
Composition type	Unified DTC between CRF process twin and machine digital twins of each sub-process.
Short description	Leveraging digital twins that have different models and generating the entire manufacturing, which provides efficient operation and maintenance for operator 1) Applying a meta-model to align individual machine twins with the CRF process twin, using standardized input/output data flows for improved interoperability. 2) Advanced analytics and optimization capabilities provided through the independent of machine-specific languages or protocols 3) Support for a data-driven digital twin that enhances predictive maintenance and process efficiency 4) Selection and application of machine digital twins through a unified digital twin inventory 5) Facilitating a system-of-systems approach where independent digital twin systems work collaboratively towards common manufacturing objectives. 6) Ensuring the reusability of machine digital twins for various applications,

	minimizing the need for developing new digital twin systems
Stakeholders	Machine Operators, Process Engineers, Data Scientists, Maintenance Personnel, Equipment Vendors, Quality Assurance Teams.
Relevant standards	ISO 15386 to construct meta-models. ISO 10303 to describe product data representation. W3C ML Schema Core Specification to describe AI modelling for digital twins. ISO 16400 and IEC 62832 to describe behaviour models for digital twins.
Standardization needs	ISO 23247-6 digital twin composition to describe how to search, select individual digital twin and exchange data by deploying interoperability between them.

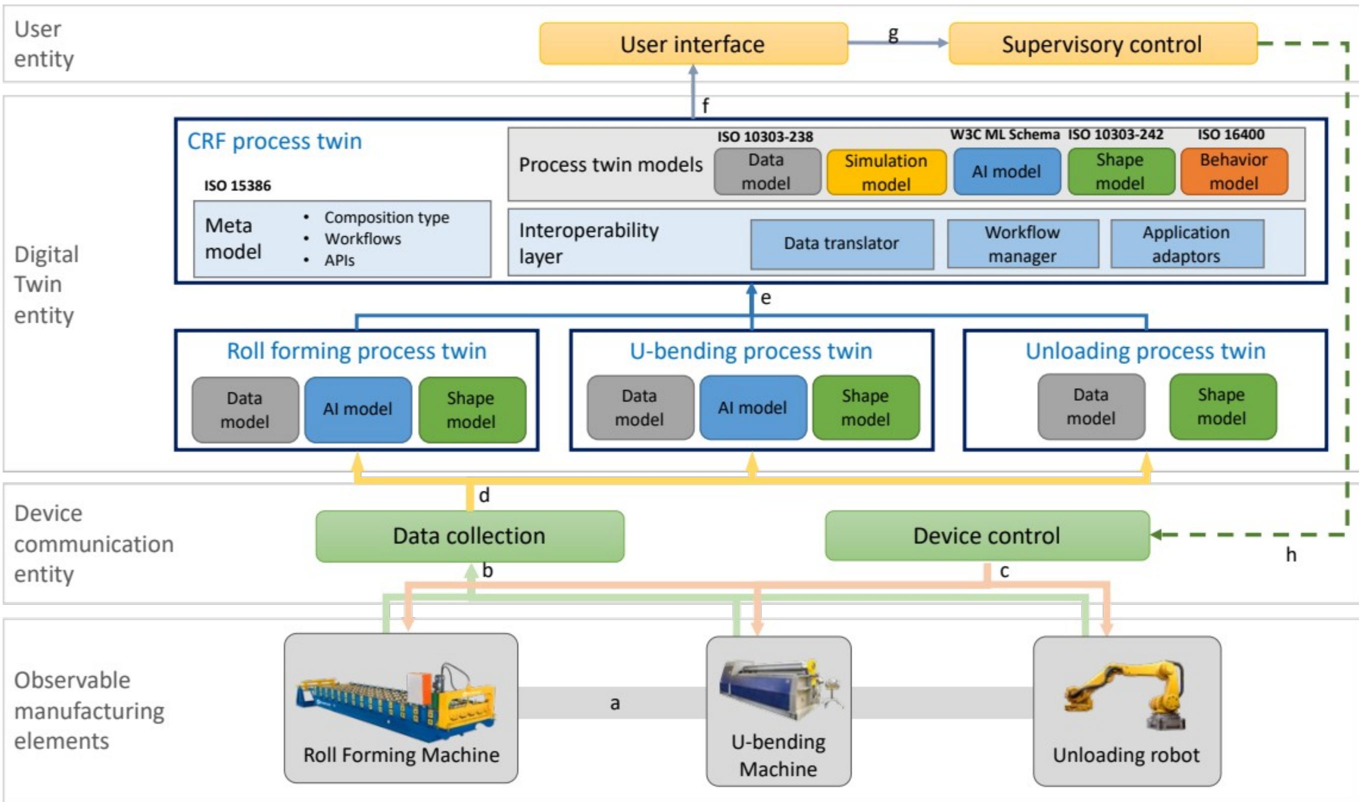
C.2 Operation sequences

C.2.1 Process flow

Cold Roll Forming (CRF) process is separated into three sub-processes as below.

— Roll forming: The process starts with flat metal sheets or coils being fed into the roll forming machine, which consists of several pairs of rolls arranged in sequence. As the metal passes through each pair of rolls, it is progressively bent into the desired shape. For refrigerator inner cases, this shape can include specific grooves or patterns characteristic of the refrigerator's design.
— U-bending: After the initial roll forming, the U-bending machine is used to make precise bends at designated points along the metal sheet. This step is crucial for creating the U-shaped profiles often required for the corners and edges of the refrigerator’s inner case. The U-bending machine ensures that these bends are accurate and consistent, contributing to the overall structural integrity and aesthetic of the final product.
— Unloading: Once the metal sheet has been shaped and bent to specifications, an unloader robot is typically used to remove the finished product from the machine and place it onto a conveyor or storage area. This automation step increases efficiency, reduces manual labor, and minimizes the risk of damage to the finished inner case.

Process flow of CRF process including three machines of each sub-processes are shown in Figure A.3.



Key

a	connection of physical elements in production pipeline
b	process data stream to data collection entity
c	control commands to OMEs
d	process data stream to digital twins
e	data exchange between digital twins and interoperability layer
f	data exchange between digital twin and user entity
g	application interface to supervisory control
h	commands to device control entity

Figure C.1 — CRF process and sub processes digital twin composition

C.2.2 Phase 1: DTC requirements establishment

- Determine the requirements of the CRF process for manufacturing refrigerator inner cases, including roll forming, U-bending, and unloading processes.
- Set clear objectives such as improving process efficiency, enhancing anomaly detection, and optimizing production schedules.

C.2.3 Phase 2: DTC design

- Design the overall architecture of the digital twin system, including how the high-level process digital twin (i.e., CRF process digital twin) will interact with individual sub-process twins.
- Create a meta-model of the CRF process twin, detailing the relationships between the digital twins of each sub-process and linking parameters for the input and output of each digital twin.
- Design the interoperability layer in the CRF process digital twin. This includes data models used in individual digital twins, data formats and schemas depending on the applications, protocols for data exchange, and the workflow connecting them in sequence.

C.2.4 Phase 3: DTC development

- Develop CRF digital twin with the designed interoperability layer functionalities.
- Update meta-models of individual digital twins, including the relationship with the CRF process, API information, and input-output parameter mappings.

C.2.5 Phase 4: DTC operation

- Launch the digital twin system on the manufacturing floor. Connect individual twins to their corresponding physical machines and to the CRF process digital twin for centralized control across sub-processes.
- Forward data gathered by individual digital twins to the CRF process twin. Translate the data into a common format to align with application requirements.
- Execute simulations and services such as simulating different production scenarios, predicting potential issues, and optimizing schedules.

Annex D
(informative)

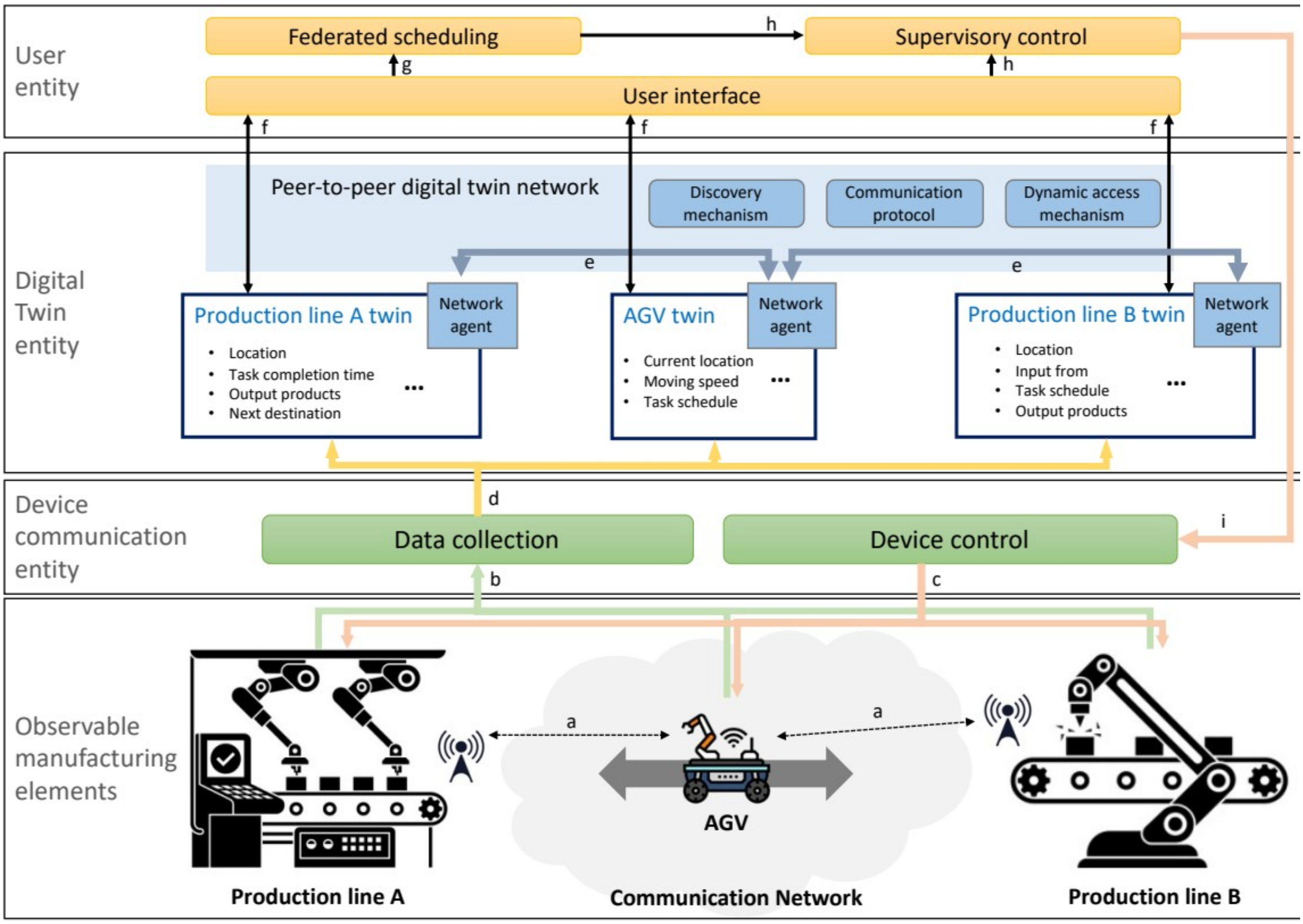
Federated digital twin composition use case —Automatic Guided Vehicles (AGVs) in manufacturing floor

D.1Overview

Use case name	Dynamic digital twin composition for Automatic Guided Vehicles to enhance productivity and flexibility
Scope	Dynamically compose the digital twin of AGVs with digital twins of production lines, machines, and supply chains, enabling flexible AGV control and optimization across various tasks and environments for improved productivity and adaptability.
Initial (Problem) situation	AGV digital twins currently focus on route configuration and optimization. Still, they are isolated and lack dynamic interaction capabilities with evolving production environments. The shop floor configuration can change frequently, either as station placement or speed policies on different zones. It is challenging to adapt AGV operations to the changing demands of various production lines, which can limit operational flexibility and efficiency. The operation of AGVs needs to be adapted in real-time based on the conditions and changes on materials or products, operation flow between processes, and requirements for manufacturing goals.
Objective(s)	To connect digital twins of AGVs and facility twins to enable material and goods control from supply chains to the shop floor. To connect AGV digital twins with process and material twins to simulate and optimize the manufacturing workflow, enhancing responsiveness to changes and supporting manufacturing goals.
Composition type	Federated DTC between AGV digital twins and production line digital twins
Short description	Implementing a dynamic digital twin composition for AGVs to 1) Enable real-time interaction with different production line processes; 2) Enhance AGV task adaptability and routing efficiency; 3) Support optimized decision-making through interconnected digital twins; and 4) Improve production line agility and reduce system bottlenecks.
Stakeholders	Production Managers, AGV Operators, System Integrators, IT Specialists, and Process Engineers.
Relevant standards	OPC-UA to communicate locations and status from AGVs station.
Standardization needs	ISO 23247-6 digital twin composition to describe how to dynamically discovery, join and dissolve peer digital twins in federated system.

D.2 Operation sequences

D.2.1 Process flow



Key

a	wireless communication between AGVs and production lines
b	process data stream to data collection entity
c	control commands to OMEs
d	process data stream to digital twins
e	data exchange between digital twins through peer-to-peer network
f	data exchange between digital twins and user entity
g	application interface to federated scheduling
h	application interface to supervisory control
I	commands to device control entity

Figure D.1 — Automatic guided vehicle and production line digital twin composition

D.2.2 Phase 1: DTC requirements establishment

- Determine the requirements for integrating AGV digital twins with production line digital twins. Focus on enhancing productivity, flexibility, and adaptability in real-time.
- Establish clear objectives such as enabling real-time interaction with production processes, improving AGV task adaptability, optimizing routing efficiency, and supporting manufacturing goals.

D.2.3 Phase 2: DTC design

- Design the architecture of the digital twin system, focusing on how AGV digital twins will dynamically interact with production line digital twins in a peer-to-peer network.
- Develop a meta-model that includes the relationships between the digital twins of AGVs and production line machines.
- Design mechanism for dynamic discovery, joining and dissolving within federated system.
- Define data model and protocol to use for communication in peer-to-peer network.

D.2.4 Phase 3: DTC development

- Create digital twins for AGVs and production lines, capturing their physical attributes and operational behaviors.
- Implement peer-to-peer network for digital twins, ensuring they can join and leave the system as needed.
- Implement analytics to monitor performance, optimize AGV tasks, and improve routing efficiency.
- Establish systems to gather real-time data from AGVs and production line machines, enabling continuous monitoring and feedback.

D.2.5 Phase 4: DTC operation

- Launch the digital twin system on the manufacturing floor, including network capabilities.
- Use the federated digital twin system to track AGV movements, production processes in real time.
- Continuously gather data from AGVs and production lines to detect anomalies and identify areas for improvement.
- Utilize the digital twin system to simulate different scenarios, predict potential issues, and optimize AGV routes and tasks.

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