International Organization for Standardization
Organisation internationale de normalisation
Международная организация по стандартизации

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ISO/TC 184

Ad Hoc Group: Data Architecture of the Digital Twin

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Introduction

During the 13 December, 2018 meeting of the ISO/TC 184 Chairman’s Advisory Group the topic of work currently underway through a partnership of France, Germany and Italy on the “Administration Shell” was discussed. “Administration Shell” is a proposal currently circulating within the “Platform 4.0” initiative from WG Standardization of the trilateral cooperation between France, Germany and Italy. In the discussion, it was noted that there is currently no standards based foundation within ISO for the data architecture of the “Digital Twin”.

Current work between ISO and IEC through JWG 21 is working on a reference model for Smart Manufacturing and is focused on the manufacturing aspects of the product lifecycle. Further, the Smart Manufacturing Coordination Committee is aligned on sharing between ISO Committees on the topic of Smart Manufacturing. That said, members of the ISO/TC 184 AG agreed that digitalization of the product is distinctly different from Smart Manufacturing. Concepts like “Digital Twin” and “Digital Thread” should be formalized through a rigorous, standards based approach.

This Ad Hoc group has been formed to study the formalization of the “Digital Twin” and assess the current portfolio of standards developed within ISO/TC 184 and relevant liaison committees against the resulting data architecture proposal.

By consensus of the members of the ISO/TC 184 AG, each SC shall nominate a maximum of two members to participate in the Ad Hoc. The members are:

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Experts from ISO/TC 184 and its SC's were called upon to support specific actions as required.

The group kicked off the action on 13 March with a Zoom meeting and met weekly in virtual Zoom meetings through 3 July, 2019 targeting a review with TC 184 at its Plenary scheduled for 25 – 26 June, 2019 in Gaithersburg, Maryland USA.

1. Scope

The current draft technical report of IEC/TC 65 ISO/TC 84 JWG 21 on Smart Manufacturing Reference Models has referenced in passing the Digital Twin as: "Digital representation of physical individuals as well as of virtual entities in an information framework that interconnects traditionally separated elements and provides an integrated view throughout life cycles (digital twins and digital thread)." While the term "Digital Twin" has not been formally defined as part of an international standard and multiple definitions exist in the industrial context, the definition serves to start the discussion. This digital replica, existing entirely through the representation of the asset through models has to coexist with the physical asset it represents at any point in the asset's lifecycle. In the digital domain, the data structure and content is critical. What is important from one point of view is less relevant to another point of view, yet each are expected to relate to each other for maximum utility. This data architecture, when properly constructed, will provision for an asset's digital definition in a common architecture framework that enhances interoperability and increases the value of the Digital Twin in the industrial setting.

In addition to the work from JWG 21, a whitepaper published as part of Platform Industrie 4.0[1] refers to the asset administration shell (AAS) as the information related to the components, or assets, within Industry 4.0. The AAS addresses, in part, consistency across Digital Twins, data sharing, and integration across Digital Twins. In addition, the implementation of AAS appears to be centered on the automation and control stakeholder community while Digital Twin concepts are being discussed in multiple industry stakeholder communities.

This Ad Hoc Group is charged with:

- Defining the Digital Twin in order to establish common terminology across ISO/TC 184
- Drafting a proposed architecture concept of the Digital Twin
- Assessing the ISO/TC 184 portfolio of standards against the data architecture
- Propose an organizational structure to carry the work forward (Task Force, Working Group, etc.)
- Making recommendations to TC 184 based on the group's work.

2. Normative References

This document has no normative references.

3. Digital Twin background and definition

The origin of the Digital Twin is attributed to Michael Grieves and his work with John Vickers of NASA. With Grieves presenting the concept in a lecture on product life-cycle management in 2003 [2]. Grieves and Vickers saw a world where a virtual model of a product would lay at the heart of product life-cycle management. They defined the Digital Twin as a virtual representation of a physical product containing information about the said product.

In this early work the Digital Twin was described as consisting of three components: a physical product; a virtual representation of that product; and, the data connections that feed data from the physical to the virtual representation.

Others have produced various definitions for Digital Twins over the years and the most prominent of these have been gathered in a JTC1 Technology Trend Report [3].

Modeling of physical individuals and their lifecycle process (Digital thread) has long existed in areas such as defense and oil and gas industry, mainly to support service and maintenance. What is new is the improved, lower cost technologies for sensing and making data available over the internet with abilities to connect the digital models to their real counterpart, addressing needs for fast (low latency) updating with higher resolution. Since manufacturing involves the generation of massive amounts of measured data, a central issue is also how to analyze this data, aggregating it into information that is useful for e.g. understanding and improving the processes and predicting their direction, generating a holistic framework based on measured data and digital models.

The Ad-Hoc group which represents experts from a wide range of industrial fields from discrete part manufacture to construction to process industries, identified that a broad base definition is required to capture the manner in which users in the industry are referring to Digital Twins. Further sub-classification of the term is then necessary to capture the complete set of semantics that practitioners in various fields associate with the term.

What follows are two definitions and a series of examples that clarify the context by which the definitions are used. The rational for two definitions lies in the broad scope of what may or may not be a Digital Twin. For that reason, it is important to have a level of abstraction first followed by a specificity to establish context. Further refinement is expected over time as more consensus is built with additional stakeholders.

Digital Twin 1
a fit for purpose digital representation of something designed to support some decisions related to it.

Digital Twin 2
a fit for purpose digital representation of some realized thing(s) or process(es) with a means to enable convergence between the realized instance and digital instance at an appropriate rate of synchronisation.

Note: The Digital Twin may exist across the entire life-cycle and can leverage aspects of the virtual environment (high-fidelity, multi-physics, external data sources, etc.), computational techniques (virtual testing, optimisation, prediction, etc.), and aspects of the physical environment (historical performance, customer feedback, cost, etc.) to improve elements of the overall system (design, behaviour, manufacturability, etc.).

In order to appreciate the working definitions, it is helpful to use some examples where the definitions are refined through type casting. Several types of Digital Twins are noted below. The list is not exhaustive and simply conveys the flexibility of the definition in addressing a broad range of concepts that are currently being used in industrial settings.

In design, the focus is on innovation where change is normal in an iterative process where history (versioning) matters. Design is open-ended and innovative, turning ideas from many perspectives into a specification of an individual that meets the requirements. Realization, on the other hand, aims for efficient execution in a predictable and stable process when turning the design specification into a real individual. While striving for repeatability, one specification could result in differing real individuals due to variation in the exact implementation process.
While a digital twin during and after manufacturing is a representation of a specific realized individual updated to reflect reality, the design digital twin thus typically represents a type, has versions and history, and could represent a whole family of variants together with their configuration rules.

Digital twin for engineering design

The Digital Twin for engineering design is a virtual representation of the design at the point of interest in the lifecycle. In the conceptual development and proposal phase, the Digital Twin consists of models that manage requirements and demonstrate the allocation and validation of requirements to functional models with behaviour.

An example would be the allocation of requirements for flight as consumed in a set of models that demonstrate flight behaviour and aerodynamic response. Additional representations of the models can include other responses like thermal and electromagnetic effects. In this phase of the product lifecycle, the design is refined and iterated upon through many cycles, often to optimize a particular component or aspect of the product performance. As the design progresses, the digital twin turns to a more complete virtual representation of the physical design to include geometry and related data. The released engineering design then becomes one of “as-built” when compared to the manufacturing aspects that the physical production induced including deviations, waivers, and alterations from the engineering released configuration.

Finally, the engineering physical design is support related where field experience is added to the representation space to include support and service perspectives. At all points along the journey, dynamic, real-time assessment of the system's current and future capabilities are incorporated through either simulation or physical experience feedback.

Digital Twin for manufacturing processes (DTMP)
The group working on Digital Twin Manufacturing Framework (AWI/ISO 23247) define a Digital Twin as a model of a physical element or production process that can be observed in the real world. A Digital Twin Agent uses messages streamed from sensors to synchronize the current state of the Digital Twins within its scope with their corresponding physical elements or production processes.

Digital Twin for manufacturing systems (DTMS)
DTMS is the digital model of physical assets such as man, machine, material, and method, collectively known as 4M, and the environment (1E) in the manufacturing system. The twin provides the digital replica of the elements (sometimes referred to as "digital masters"); the dynamics of how IoT or smart devices operate to transfer data from the physical system to the digital counterpart; and, data about the physical asset throughout its lifecycle including historical data (sometimes referred to as the "digital shadow"). Synchronization of the physical model and the corresponding virtual counterpart through sensors is an important aspect of DTMS.

A DTMS is only meaningful when it supports the enhancement of a KPI. Examples of KPIs in the case of manufacturing systems include health of machine tools, health of cutting tools, health of product (quality), and health of environment (energy, emission, waste).

This definition for DTMS corresponds to the definition of Digital Twins by Stark et al [4] adding the notions of method and environment as well as including the mechanics of information transfer in the definition.

Digital Twin for Built and Natural Environment (DTC)
DTC is defined based on the Gemini principles published by Centre for Digital Built Britain [5]. This report defines a Digital Twin as "a realistic digital representation of assets, processes or systems in the built or natural environment. What distinguishes a Digital Twin from any other digital model is its connection to the physical twin. Based on data from the physical asset or system, a Digital Twin unlocks value principally by supporting improved decision making, which creates the opportunity for positive feedback into the physical twin."

Digital Twin for process industries (DTPI)
The Digital Twin for process industries is defined as a collection of digital models including process engineering models, physical system models, application and system models, workflow models, communication models, and services models. Different digital models originate from and are maintained by different work processes, applications and systems with different owners, so tightly coupled synchronization of the models is impractical. Instead, a more loosely coupled, approach is taken with the multiple distributed, but federated digital models, which are synchronized at various contextually appropriate rates, often using sub-sets of data which have been validated with each other using event-driven, asynchronous IT methods.

4. Approach toward implementation

To have a definition of the Digital Twin and contextual examples of the definition in practice is necessary but not sufficient. To be of practical use to industry, the definition requires an architectural configuration including relationships to existing data structures. In the conventional case, a concept model is developed that is decomposed into a data model or set of data models that relate to the concept. A general model that is commonly used in standards development is shown in Figure 1. In the development process, each of these concepts are fully explored and memorialized in a relevant standard. ISO 10303 is a good example of this approach. All of this is a bit premature to have in this document. That said, what can be described is a landscape perspective that outlines what elements are needed for the digital twin.

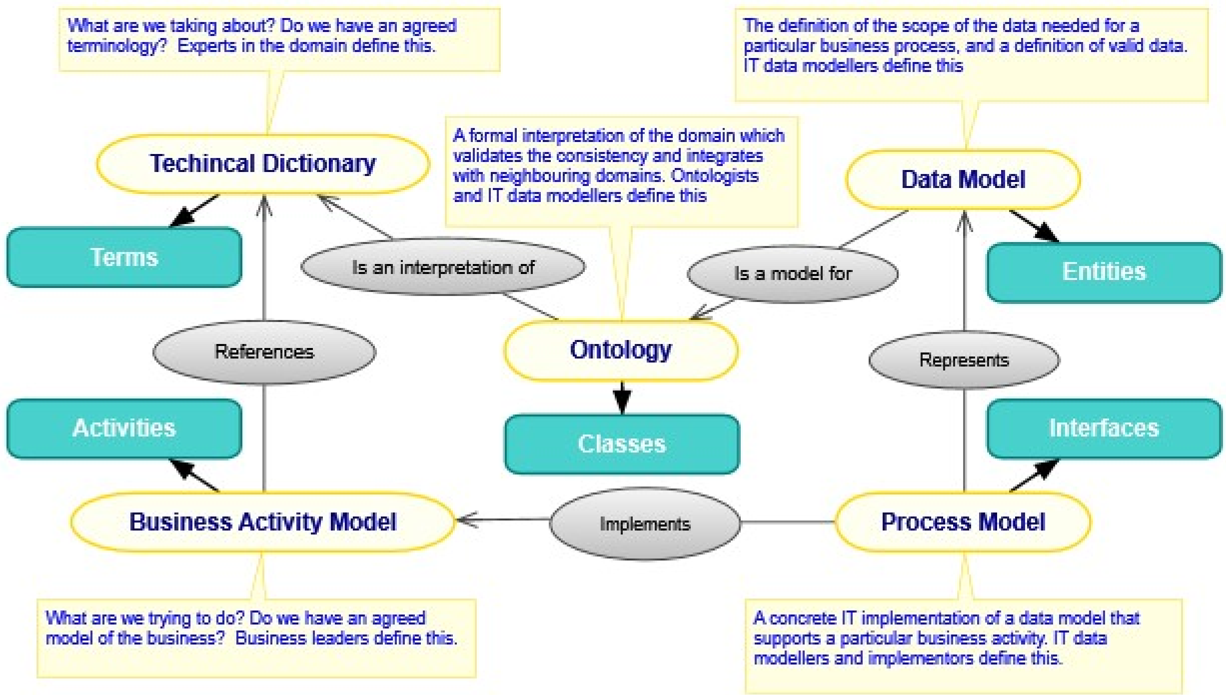

Figure 1: Conceptual data model architecture for any digital asset [6].

A landscape model gives a higher level perspective of the system of interest. In this case, the system of interest is a Digital Twin. There are two perspectives of several that could be described in a landscape model that are of interest to us. The first is a Management perspective while the second is a Support perspective. Figure 2 gives a general landscape model where the system of interest is noted by the “Domain Space” in the center of the diagram.

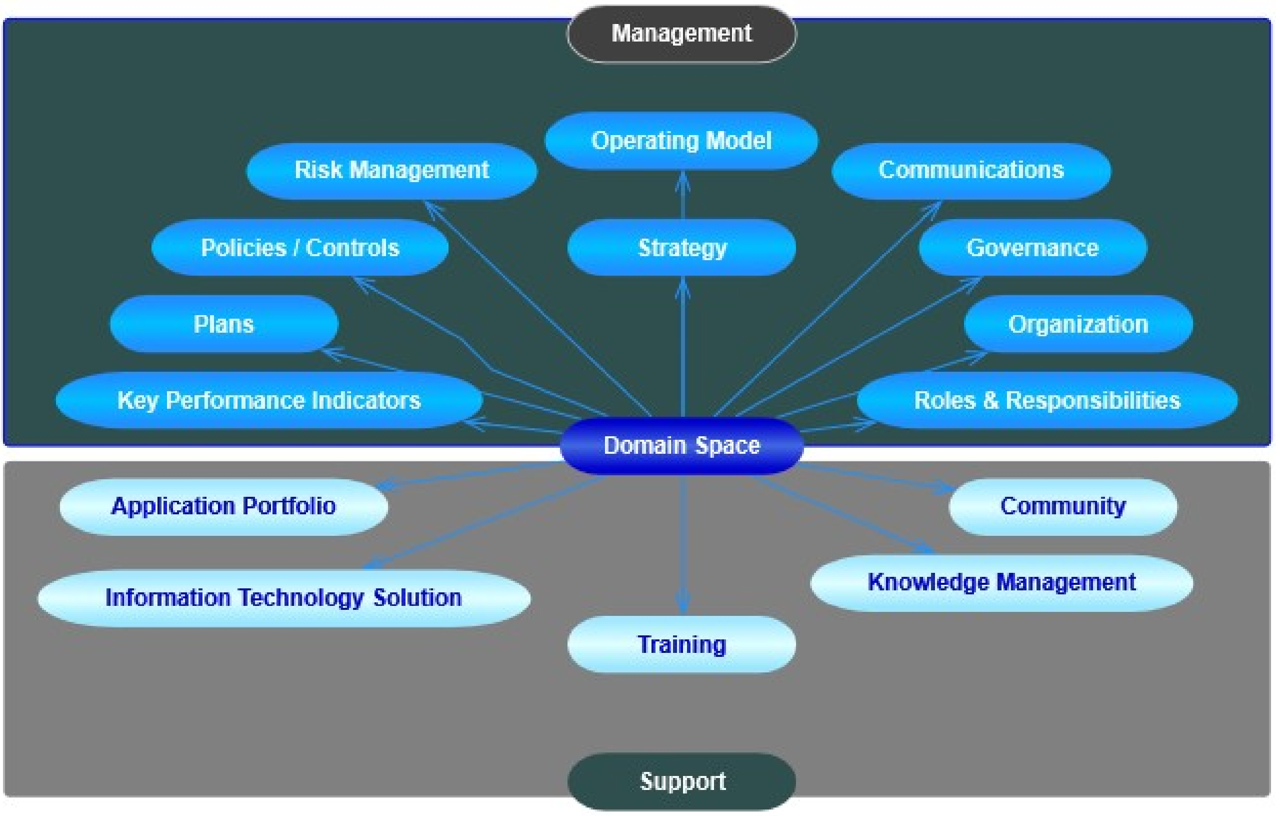

Figure 2: A representative landscape model for a system of interest [7].

The following subsections describe a landscape model built upon the foundation of ISO 9001 and example use cases for the discrete manufacturing industry and the process industry.

4.1 Digital Twin landscape model

Given the extensive work required to have a properly modeled data architecture for any topic, the group concluded that it is too early to have such detail settled now. Instead, the concept of a landscape approach was utilized to frame the discussion.

A Digital Twin is used to support business processes and, in particular, to support decisions made in them. This means that a Digital Twin needs to be fit-for-purpose, so a Quality Management approach for managing a Digital Twin is appropriate, as illustrated in Figure 3 and provided in more detail in Figure 4 based on ISO 9001.

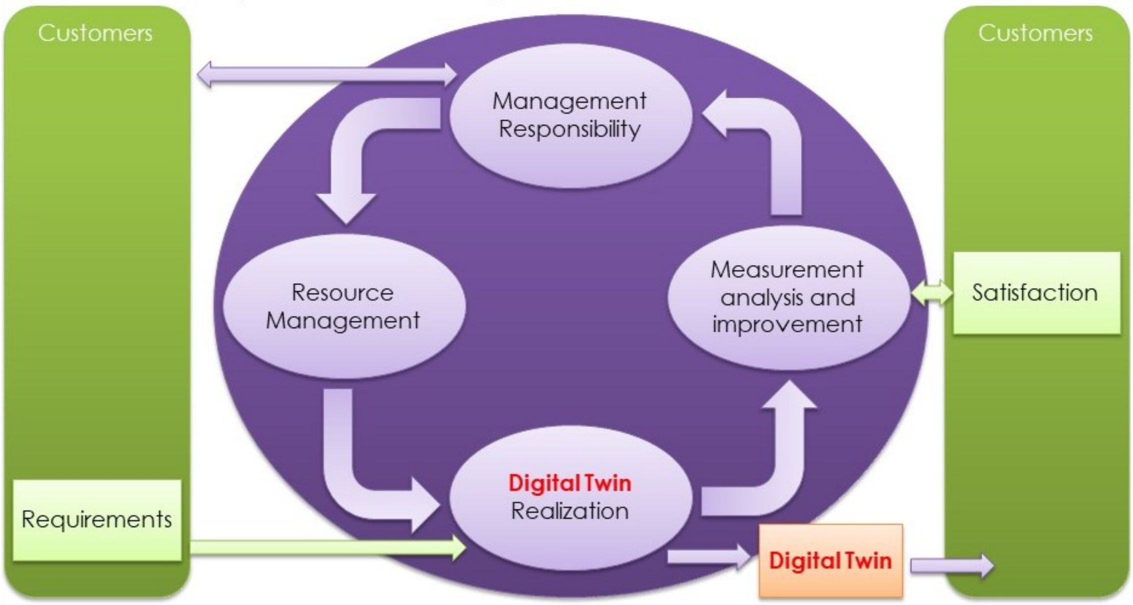

Figure 3: The ISO 9001 Quality Management Process adapted for the product being a Digital Twin.

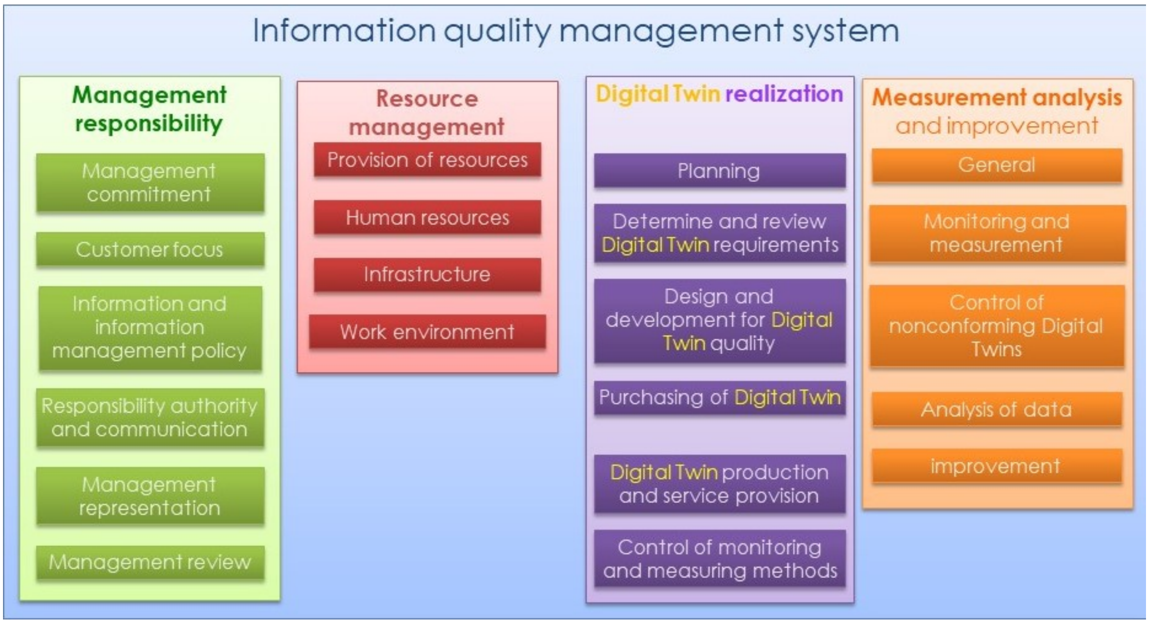

Figure 4: Detailed Quality Management Process according to ISO 9001.

These processes themselves need information to support them and this is outlined in Figure 5.

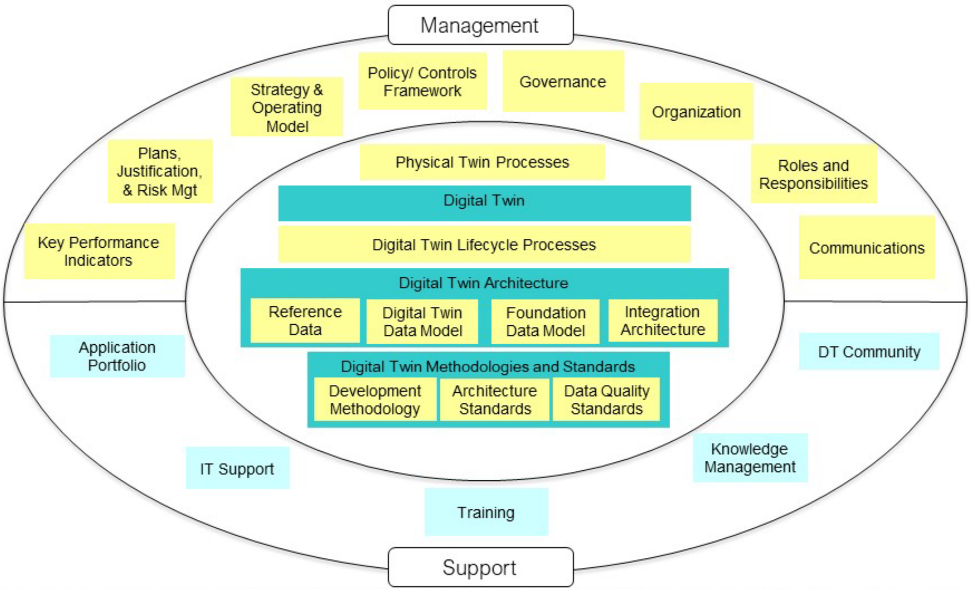

Figure 5: A Digital Twin Management Landscape.

Key to understanding the information requirements that a Digital Twin needs to support is to consider the processes for the Physical Twin. These will include the lifecycle processes for the physical twin itself, and the processes that the physical twin is used to support, which may be the lifecycle processes of another physical twin, or a core process for an enterprise. This is illustrated in Figure 6.

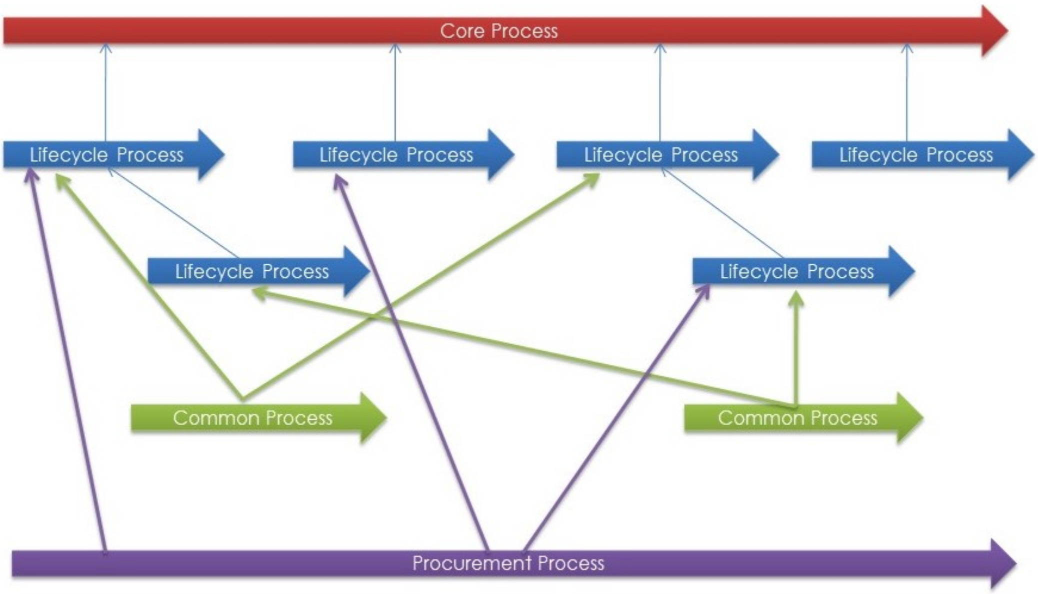

Figure 6: A general model of an enterprise's processes.

The needs for data integration as shown in Figure 7 go beyond lifecycle processes, and extend into the management and control of an enterprise, where information is brought together for levels of control from automated real time control through to profit and loss, and also through the supply chain so that data supplied with purchases is already consistent with other data that is part of the Digital Twin.

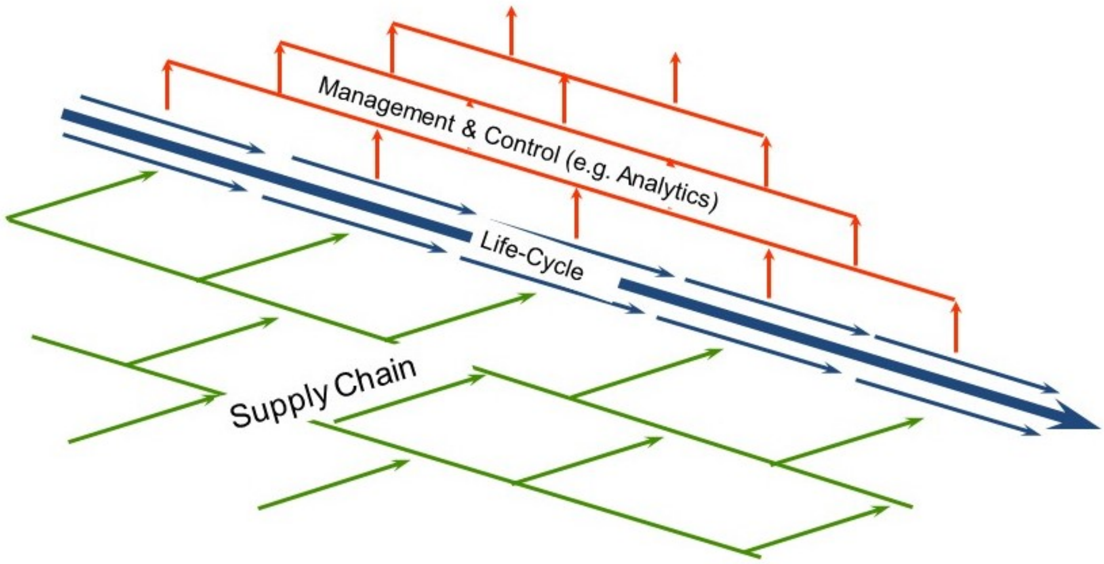

Figure 7: The dimensions of data integration and sharing over which consistency is required for a business.

We also need to consider the Digital Twin Lifecycle Processes that create and manage the Digital Twin, so we can ensure the data is fit for purpose where it is used in terms of things like accuracy, timeliness, relevance and cost.

A Digital Twin environment is supported by a Digital Twin Architecture that consists of a Foundation Model and Reference Data that together ensure the consistency of data across Digital Twins. You might optionally have a Digital Twin Data Model, though care here needs to be taken that where Digital Twin Data Models overlap, they are consistent which means it must be a simple transformation of some part of the Reference Data together with a subset of the Foundation Data Model.
The Integration Architecture is an important element. There are a number of options available. Figure 8 shows two basic logical architectures, point-to-point and hub and spoke. It is easy to see that a hub and spoke logical architecture is more efficient, and it does require the common data model and reference data we have identified here but the hub can be virtual.

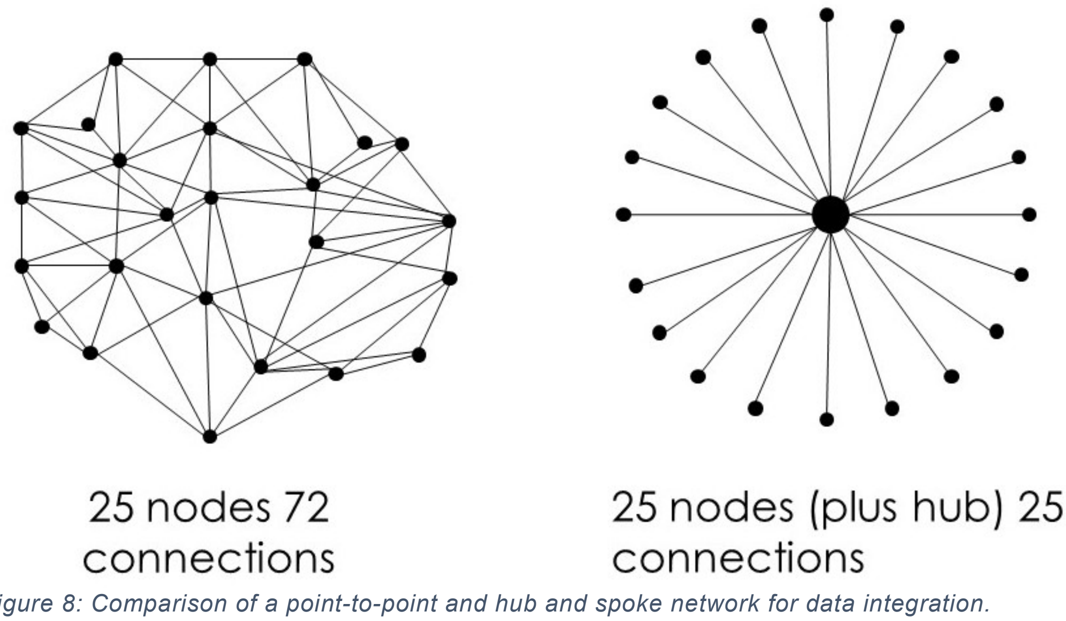

Figure 8: Comparison of a point-to-point and hub and spoke network for data integration.

Further, the links between nodes can be complex. The links may involve:

- Data transmission
- Terminology translation, and
- Data structure mapping.

The nodes are distinct datastores/files. Figure 9 shows Digital Twins without any data integration. Each Digital Twin has multiple views, each with their own data model. Mappings are required for each occasion where data needs to be shared, including mapping between data structure and translation of the terminology used by each.

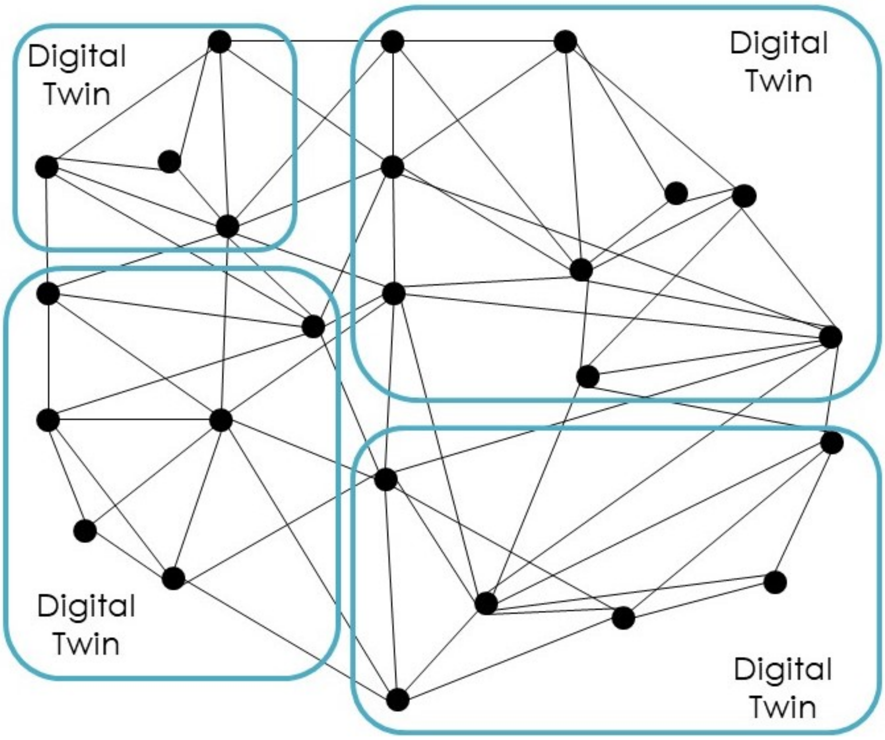

Figure 9: Digital Twins with multiple datastores/files.

Figure 10 shows an improvement on this where common master and reference data are used across the Digital Twins, so now only physical transport and mapping between data structures is required. This architecture could be supported by the Asset Administration Shell.

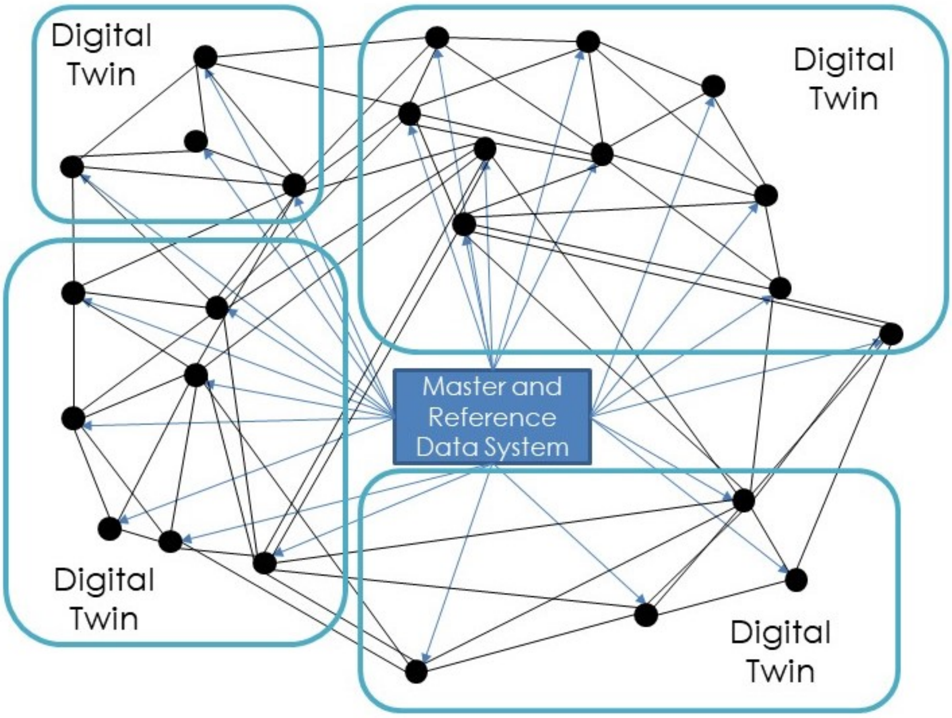

Figure 10: Digital Twins with multiple datastores/files and common Master and Reference Data.

Figure 11 shows an architecture with a messaging system where all Digital Twins are held using a common data model and reference data, which is also used to transmit data between Digital Twins as required. Where source data is created using applications that do not conform to the common integration data model, they are first mapped to it. This provides a hub and spoke architecture for both terminology and data structure.

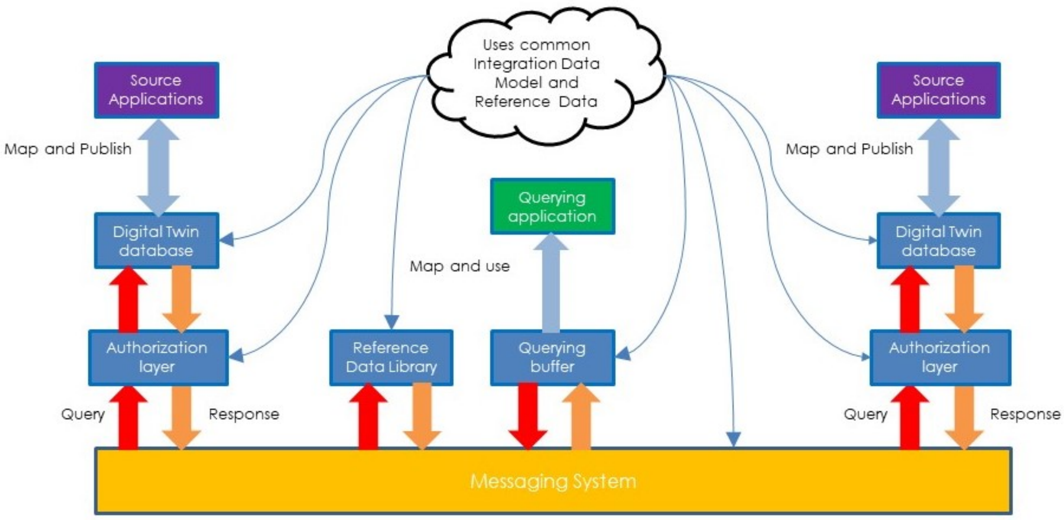

Figure 11: Digital Twins with an integrated database all Digital Twins using a common data model and reference data.

The Digital Twin Architecture needs Digital Twin Methodologies and Standards, in particular a Development Methodology, Architecture Standards and Data Quality Standards.
Other elements of the Digital Twin Landscape are in the Management and Support ring in Figure 5. These are:

- **Governance:** How decisions are made and enforced.
- **Policy and Controls Framework:** Established decisions that sets the boundaries on how Digital Twins are managed.
- **Strategy and Operating Model:** The overall approach to managing Digital Twins.
- **Plans, Justification, and Risk Management:** The detailed plans for the next steps in implementing the Digital Twin Landscape.
- **Organization:** The organizational structure of the enterprise.
- **Roles and Responsibilities:** The roles and responsibilities for performing Physical Twin and Digital Twin processes and their allocation to positions in the organization.
- **Key Performance Indicators:** Measures of the performance of the Physical Twin processes and the Digital Twin Processes.
- **Communications:** Making the enterprise aware of the changes involved in introducing Digital Twins to the enterprise and what is expected of members of the enterprise to support their introduction.
- **Digital Twin Community:** Develop and foster a sense of community among those involved in developing and operating the Digital Twin Landscape and Digital Twin Lifecycle Processes.
- **Training:** Giving members of the enterprise the skills they need to develop and operate the Digital Twin Landscape and Digital Twin Processes.
- **Knowledge Management:** Capture and disseminate learnings from developing and implementing the Digital Twin Landscape and Digital Twin Lifecycle Processes.
- **Application Portfolio:** The catalogue of the applications used by the enterprise and their involvement in the Digital Twin Lifecycle Processes.
- **IT Support:** The hardware and systems software needed to support the Application Portfolio.

Together, the elements of the Digital Twin Landscape are the information needed to support the quality of the Digital Twins in the enterprise, and the quality management process that manages the Digital Twins. The properties of data quality and the elements of the quality management process that they support is illustrated in Figure 12, and Figure 13.

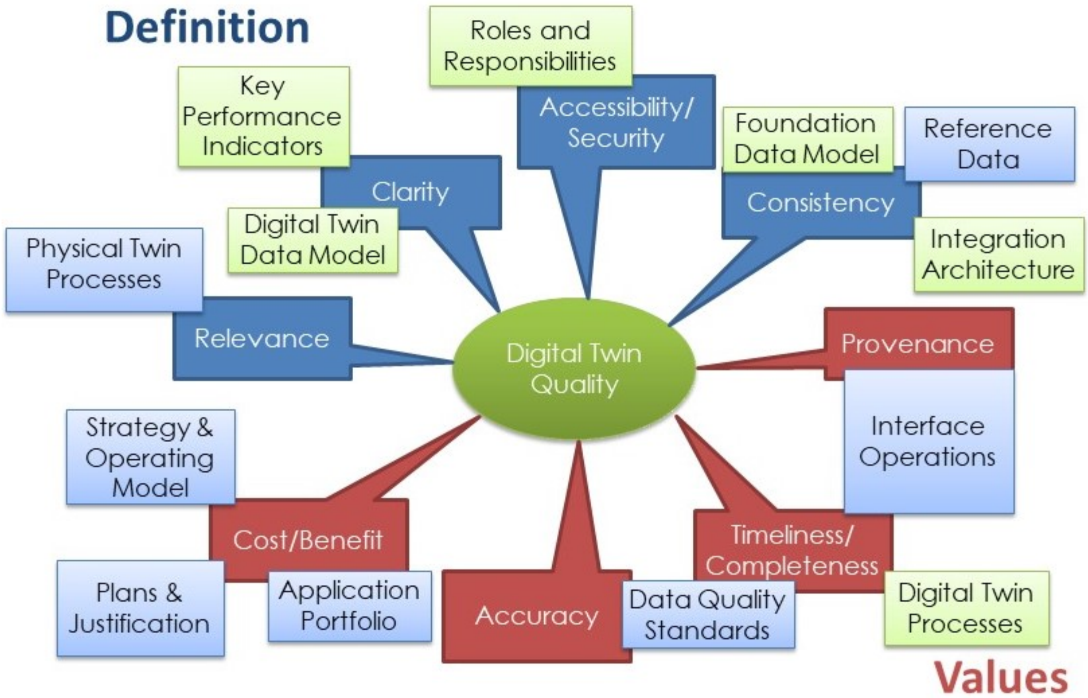

Figure 12: How the Digital Twin Management Landscape supports Digital Twin quality.

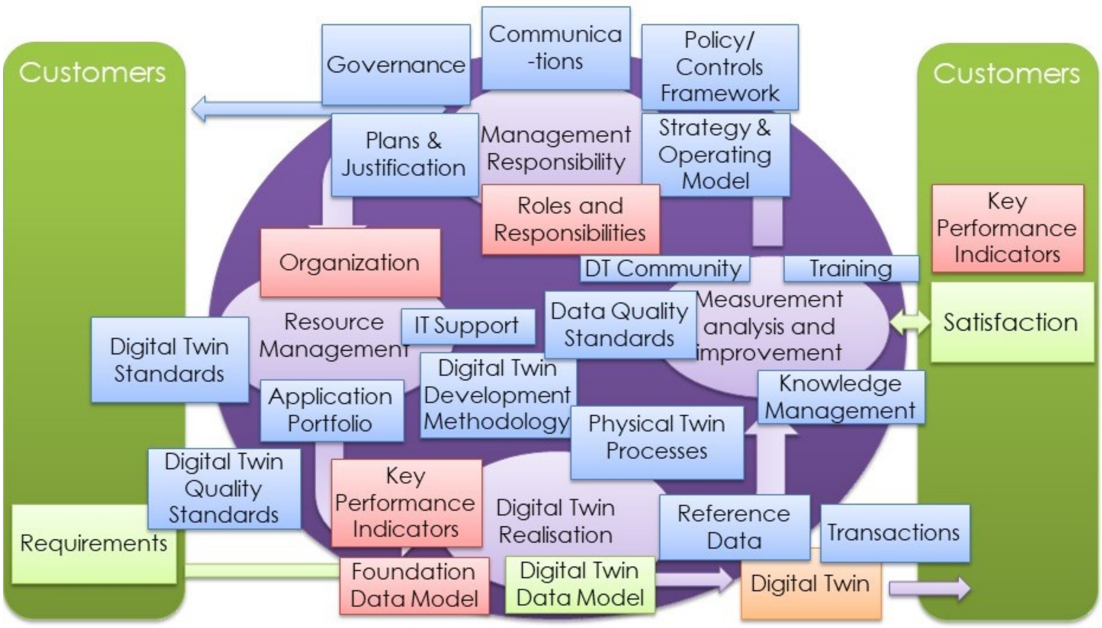

Figure 13: How the Digital Twin Management Landscape supports the Digital Twin Quality Management

4.2 Digital Twin manufacturing frameworks

Manufacturing has use cases similar to those of process plant and building management. Apart from the equipment and processes of the manufacturing system, the result of manufacturing is an asset. The twin of that asset can be used for quality control and maintenance operations. Figure 14 shows a Digital Twin life cycle model for aerospace and defense applications.

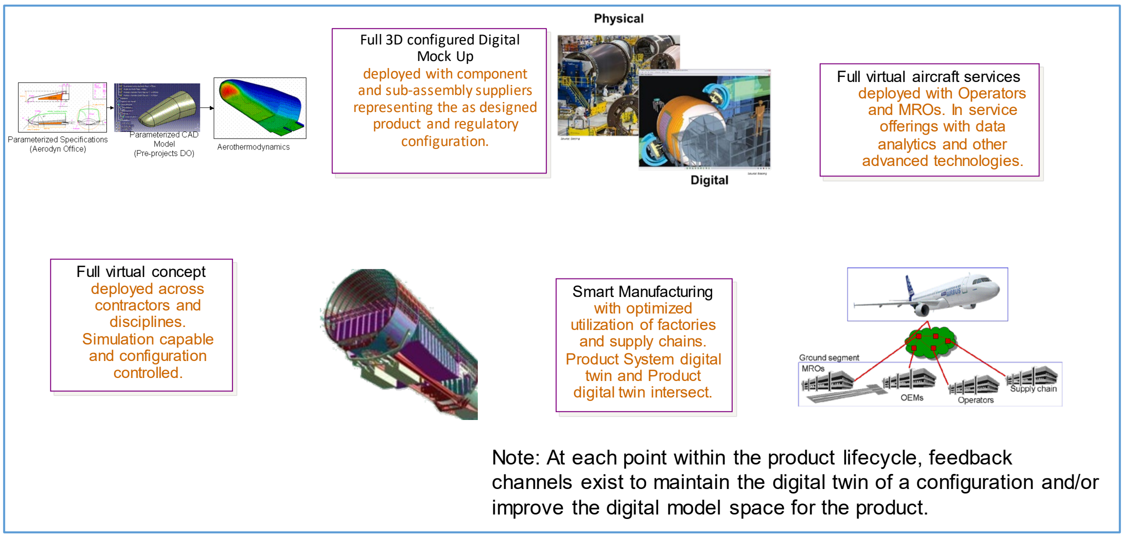

Figure 14: Digital Twin Life Cycle Model for Aerospace and Defense.

Manufacturing also is an activity that can support the building of Digital Twin models in real time. Communication signals from the manufacturing devices can be used to change the Digital Twin model during production. Measurements made on the Digital Twin model can be used to make the manufacturing more efficient.

Collecting manufacturing results in real time has at least two challenges:

a. A device such as a CNC control that is reporting all its interpolation points will produce very high volumes of data.
b. A device such as a PLC that is reporting a simple change of state (e.g. on or off) requires an intelligent system to convert that signal into a meaningful modification to the Digital Twin model (e.g. add a new punched hole).

Figure 15 shows an experiment that was demonstrated at machine tool shows in 2018. In this experiment CNC machine tools were connected to Digital Twin models using the MTConnect communication protocol. The Digital Twin models were defined by STEP and modified in real time using simulation systems. The models were measured on the machine using a digital probe and the results were communicated to other systems using the QIF data format.

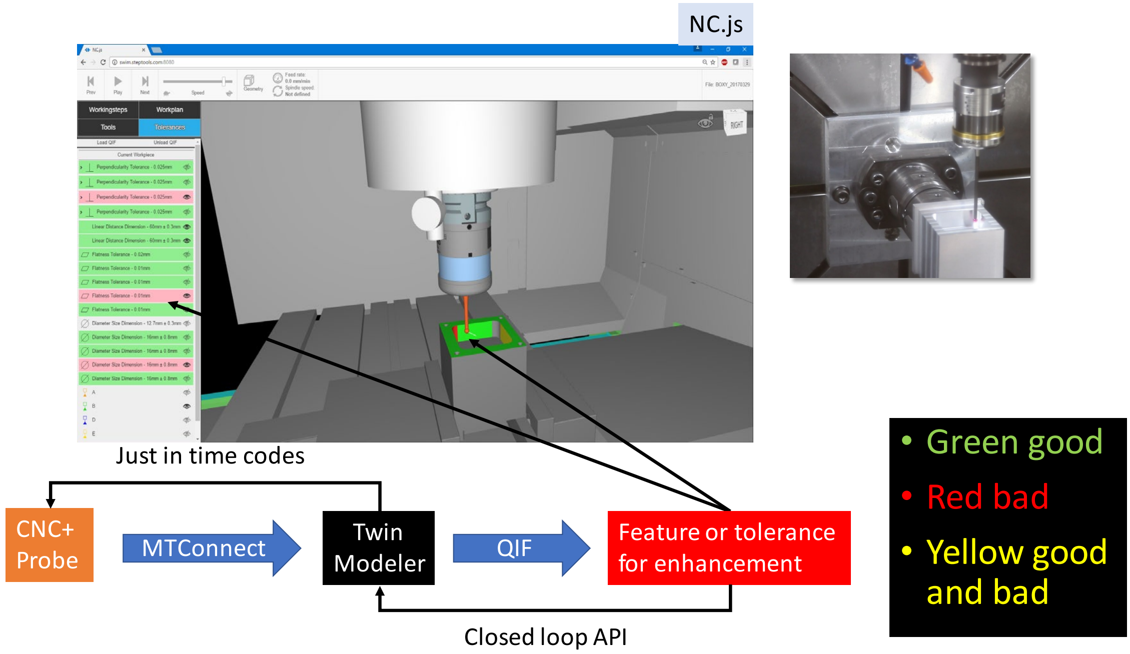

Figure 15: Real time Digital Twinning in manufacturing.

At 100Hz communication rates the simulation systems can struggle to keep pace with the manufacturing devices. Therefore, real time Digital Twin manufacturing may require systems of agents each representing the Digital Twins being manufactured by different devices. These agents will need to communicate because they will each be building part of a larger product. A Digital Twin manufacturing framework is required to enable this communication. Plug and play interoperability is essential so that different devices can be plugged into the framework as new suppliers are added to and leave the digital manufacturing network.

ISO 23247 is a new standard being developed by ISO/TC 184/SC 4 to enable plug and play interoperability for Digital Twin manufacturing. The standard uses the Internet of Things architecture to describe its framework. Discussions are on-going on the types of Functional Elements (FE's) that will be required, the types of end user systems that must be supported, and the types of communication protocols that will be necessary to communicate messages between them all.

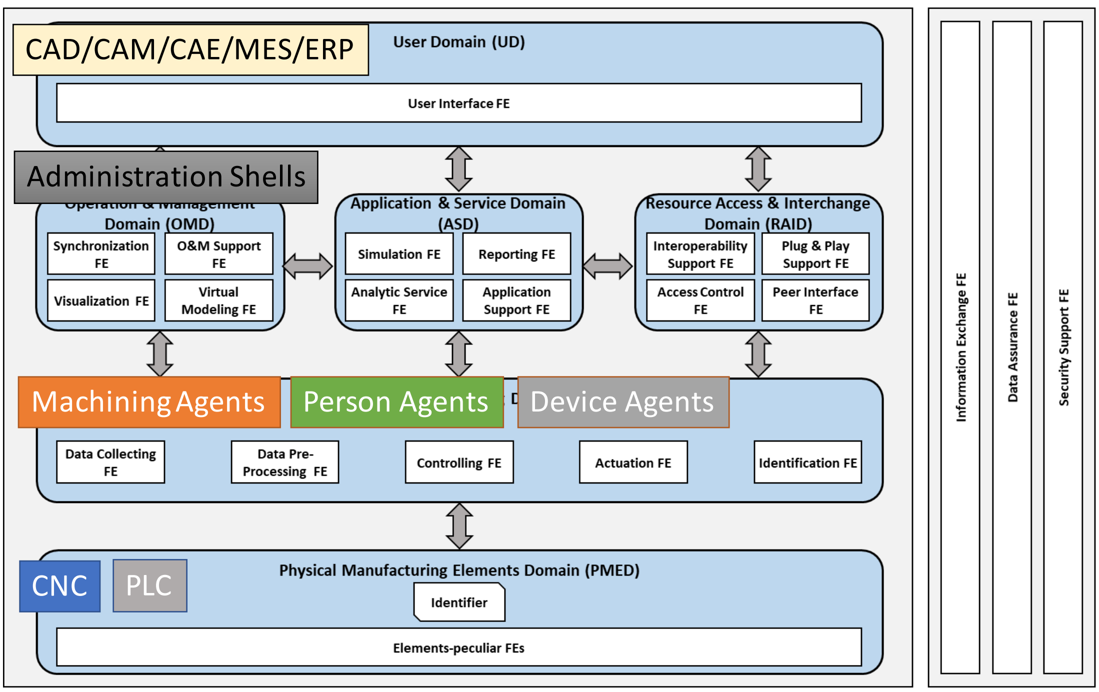

Figure 16: ISO 23247 Digital Twin manufacturing framework.

4.3 Industrial Digital Ecosystem and Digital Twins in Process Industries

ISO TS 18101-1 gives guidance for an architecture of a supplier-neutral industrial digital ecosystem. It includes a standardized connectivity and services architecture, and a standardized use case architecture with methods to specify atomically re-usable scenarios and events, which can be used to specify the characteristics of standardized industry use cases. It proposes a Supplier Neutral Industrial Digital Ecosystem to enable standards-based interoperability in process industries and their supply chains. It focuses on the Secondary Business Process for Process Industries, corresponding to a process industry view of asset life-cycle management. Figure 17 shows the Secondary Business Process in relationship to the Primary Process and to the levels defined by the Purdue Reference Architecture, which are also included in ISA-95 and IEC 62264. Figure 18 shows a more detailed view of the Asset Life-cycle.

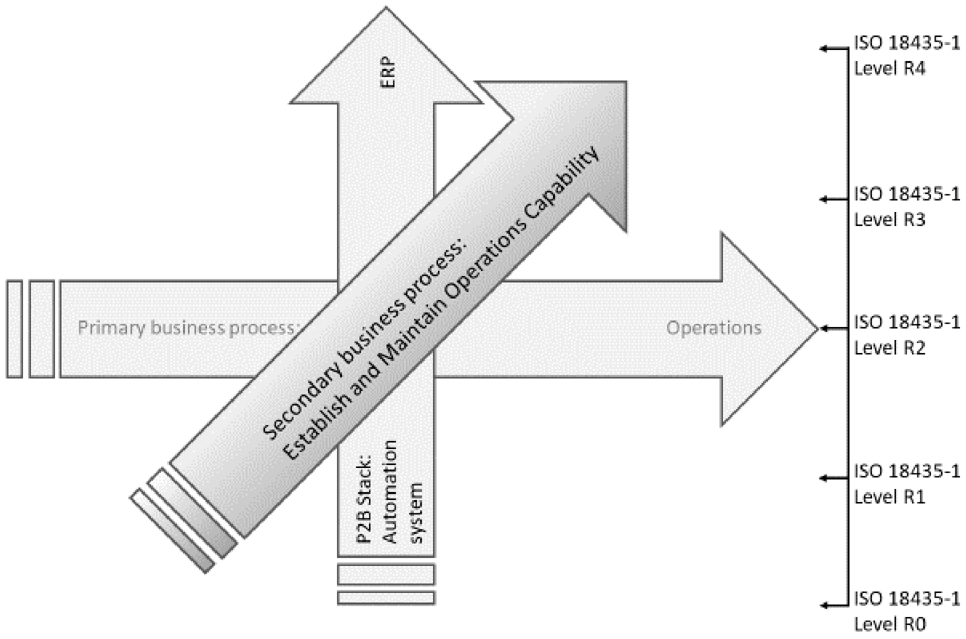

Figure 17: Secondary business process.

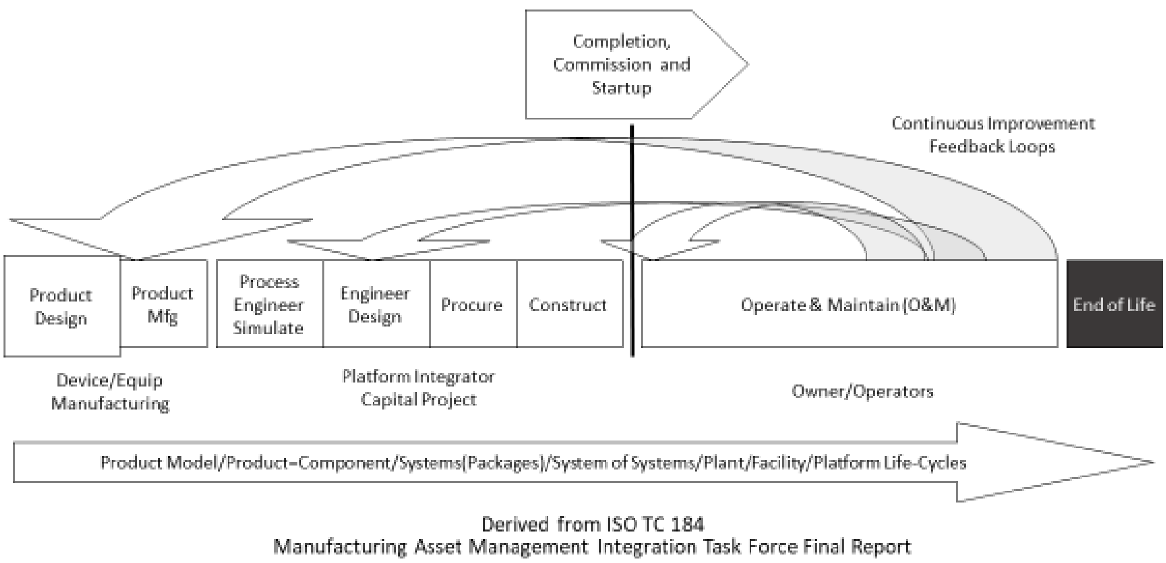

Figure 18: Secondary business process - asset life-cycle integrated view.

Such an Industrial Digital Ecosystem includes many Digital Twins, including chemical processes, systems, systems of systems, models of product, and instances of those models, business processes and risk models sufficient to enable simulation of the entire lifecycle. The included network architecture enables them to be federated as is required, along with methods to determine how they are all properly related to and synchronized with each other at any given moment in time. Collectively, these Digital Twins provide a context for sensor-based information, events and business transactions, some of which also result in changes to various aspects of the Digital Twins that are part of a given Industrial Digital Ecosystem. A Supplier Neutral approach enables individual Industrial Digital Ecosystems (and their associated Digital Twins) to be scalable from single enterprise intranets depicted in Figure 19, to extranets (with supply chain partners), depicted in Figure 20. It further enables many separate Industrial Digital Ecosystems to internetwork with each other, as is required to support business supply chains.

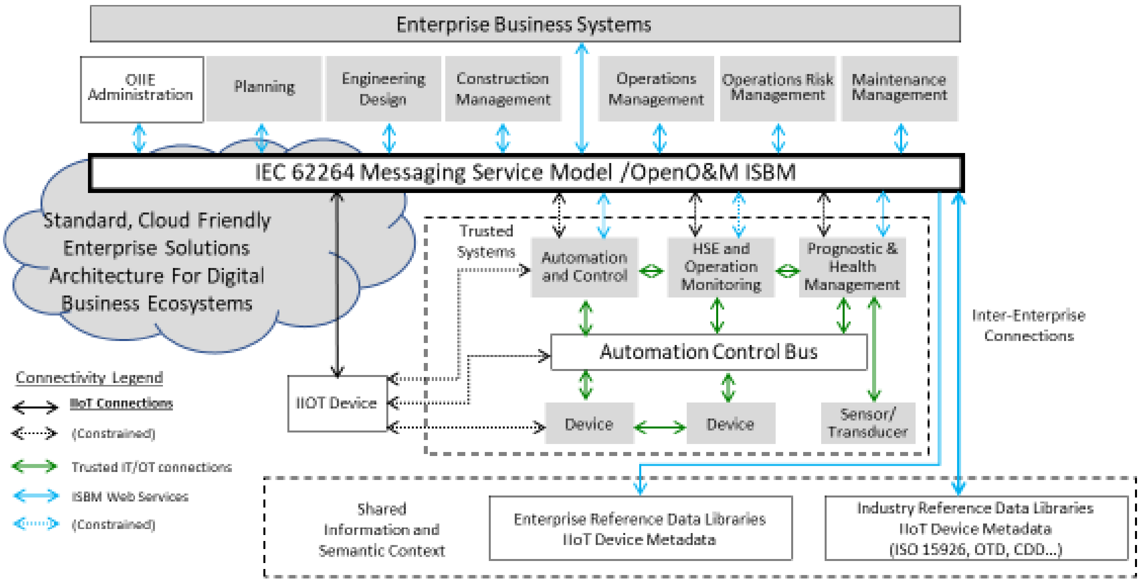

Figure 19: OIIE Intra-Enterprise Industrial Digital Ecosystem Architecture.

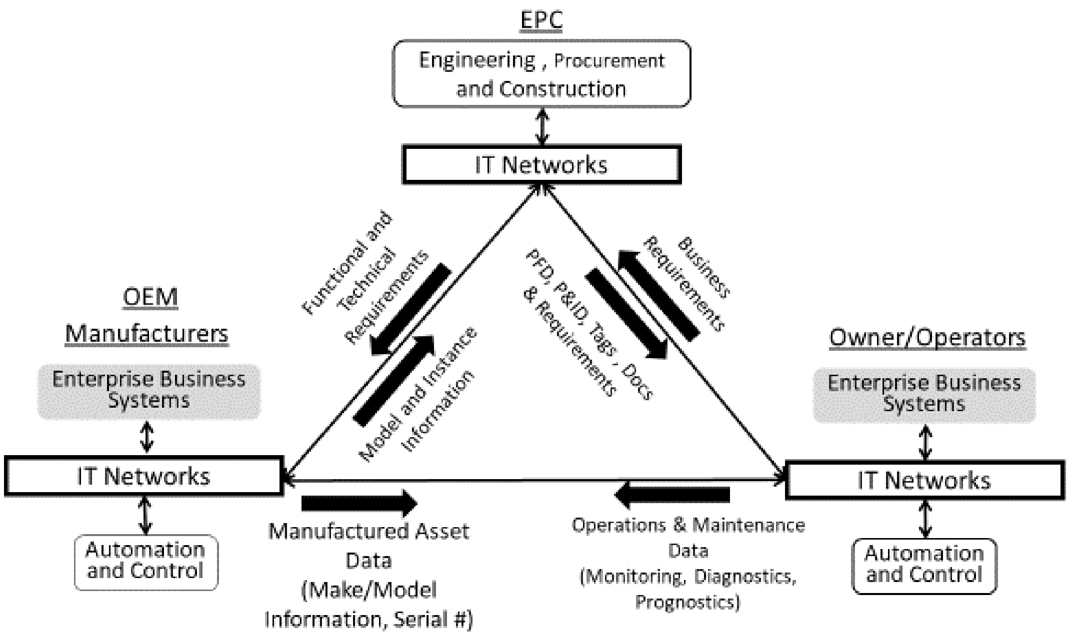

Figure 20: OIIE Intra-Enterprise Industrial Digital Ecosystem Architecture.

Standard Use Case Architecture

The Open Industrial Interoperability Ecosystem (OIIE) *Use Case Architecture* defines a standardized breakdown of Use Cases into smaller reusable parts, as well as a top-level overview of a Use Case or group of connected Use Cases. This breakdown forms a 3+1 level architecture, totaling 4 main components: *Use Cases*, *Scenarios*, *Events*, and *User Stories*. Each of the first two components decompose into the next, i.e., Use Cases decompose into Scenarios and Scenarios decompose into Events, while the fourth, User Stories, forms the “+1” as they can cross the other layers to illustrate specific events or whole use cases as required to achieve their purpose. An overview of the Use Case Architecture is shown in Figure 21.

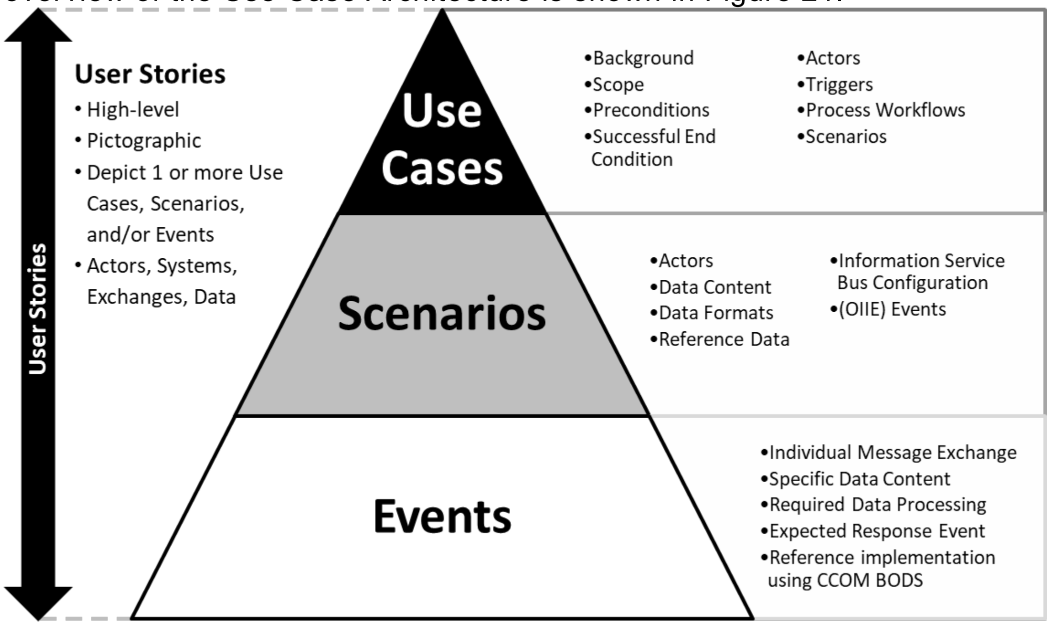

Figure 21: OIIE use case architecture overview.

Use cases

A Use Case provides a general description of interactions to achieve an (interoperability) goal within a specified scope and background context. The description includes the actors (systems or people) that are interacting, any preconditions and triggering events/conditions/use cases, the success case, a main success workflow (and possibly other workflows, e.g., exception flows, as required), and the Scenarios that are necessary to perform those workflows.

Scenarios

A Scenario provides a specific description of a group of events that achieves an interaction detailing data and configuration requirements; multiple scenarios may be required to achieve the goal of a use case and the same scenario may be reused by the same or in multiple use cases. Items included in the description of a Scenario are: the actors involved in the interaction (usually systems only, if a person is specified it indicates a device that the person is using); the data content in general terms; required data format(s); the use of particular reference data libraries or items to ensure interoperability for the Scenario; any required configuration of the Information Service Bus (e.g., channel/topic configuration); any other infrastructure requirements (support systems that are required, etc.); and the Events required to achieve the Scenario.

Events

An Event describes an individual message exchange between systems, detailing data and processing requirements. This includes specific data content (in contrast to the general description of the Scenarios), any processing requirements placed on the recipient (e.g., if a flag is set to true, then behave in a certain way), and any expected response event such as a confirmation or a query result.
Events are still abstract in that they can be realized in multiple ways to support various mechanisms for exchange while adhering to the data and other requirements. Each Event is provided with a reference implementation. This allows events to be reused in different contexts and to support future exchange mechanisms. Moreover, remaining partially abstract allows Events to represent different types of event (note, lowercase ‘e’) where necessary.

User stories

A User Story provides a high-level graphical representation of interactions and events defined by one or more use cases and/or scenarios. They are designed to provide a business level overview of interactions and Use Cases across any level of the architecture (as necessary) using a simple graphical notation. The notation differentiates people, systems, and data/documents and connects those using arrows to illustrate interactions. A User Story consists of a number of *frames*, each frame illustrates a small portion of the Story and can be connected to preceding frames in various ways to illustrate continuity and/or use of data from a previous frame. Figure 22 demonstrates the relationships between these model elements.

Example: a user story may illustrate the various events and interactions (including person-to-person, system-to-system, person-to-system, business-to-business, etc.) involved in a series of related use cases such as the triggering of a maintenance event based on condition data which leads to the removal of asset and the installation of a new asset. User stories can simply describe a logical sequence of related use cases, rather than following a trail of ‘triggering events’ defined in the use cases.

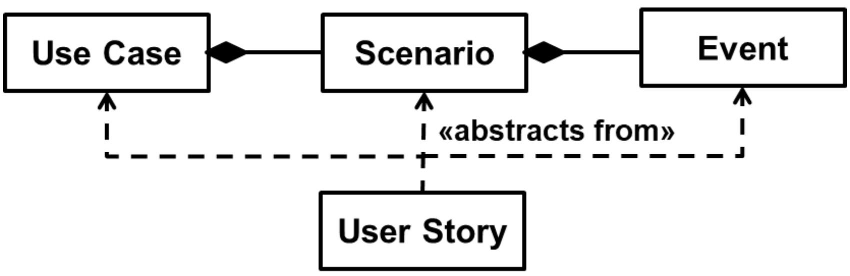

Figure 22: OIEE use case data model.

5. Asset Administration Shell

From the whitepaper published as part of Platform Industrie 4.0[1], the asset administration shell (AAS) refers to the information related to the components, or assets, within Industry 4.0. The asset administration shell is made up of a series of sub models, representing different aspects of the asset concerned. Two kinds of administration shells are provided: one for types of assets, another for physical instances of assets. Some have argued that the AAS, in and of itself, is the Digital Twin.

Although some of these models can be considered as Digital Twins, the AAS reference framework mainly concerns itself with the system infrastructure describing principles for how to structure, combine and manage models. It defines assets in terms of a header and a body, where the header specifies the contents of the body with an index in XML or JSON, defining the data content of the body models that can be STEP files, PDF files, JT files etc. Indeed, this level of tactical information definition is necessary for implementation, and the AAS aims to cover aspects of the whole life cycle of "physical" and "non-physical" assets. That said, the AAS does not address consistency across Digital Twins nor does it manage data sharing and integration across Digital Twins.

Our interpretation of the AAS is one of a framework focused on the models required within the operations phase covering configuration and discrete manufacturing. In addition, the implementation of AAS appears to be centered on the automation and control stakeholder community while Digital Twin concepts are being discussed in multiple industry stakeholder communities.

For these reasons, the authors felt it important to provide context of this work defining Digital Twin compared and contrasted to the AAS for the purpose of exposing the additional aspect work required to sufficiently complete the architecture that ISO/TC 184 standards require.

6. Impacts assessment against TC 184 standards

The team evaluated the scope of the TC and all SC's and concluded that Digital Twin is applicable to all scope within the TC.

For convenience, the base standards in TC 184 and its child committees are included in Annex A.

It is noted in this report that ISO/IEC JTC 1 recently concluded their plenary and issued resolutions from the meeting. Of interest to this group is the report provided by JTC 1/SWG 7, Emerging Technology and Innovation (JETI). In this report titled "Digital Twin", a survey of the many definitions and interpretations of the term were made resulting in a recommendation to evaluate the Digital Twin in more detail. In RESOLUTIONS ADOPTED AT THE MEETING OF ISO/IEC JTC 1, 6-10 MAY 2019 IN LAHAINA, MAUI, HAWAII JTC 1 [8] resolved to create an Advisory Group with the following Terms of Reference:

1. *Provide a description of key concepts and relevant terminology related to Digital Twin;*

2. *Identify current technologies and reference models that are being deployed in Digital Twin;*
3. *Promote the awareness of JTC 1 activities on Digital Twin outside JTC 1;*
4. *Assess the current state of standardization activities relevant to Digital Twin within JTC 1, in other relevant ISO and IEC Committees, in other SDOs and in consortia;*
5. *Identify and propose the relevant standardization issues of Digital Twin that needs to be addressed by JTC 1, covering at least foundational areas, ICT standardization needs, etc.*
6. *Engage with standards setting organizations that are involved in Digital Twin standardization as approved by the AG on Digital Twin.*
7. *Prepare a report and recommendations to JTC 1, which may include proposed New Work Items.*

Membership is open to:

1. *Experts nominated by JTC 1 National Bodies;*
2. *One representative per JTC 1 Liaison Organization and per approved JTC 1 PAS Submitter;*
3. *One representative per JTC 1/SC, JTC 1/WG, relevant ISO and IEC Committees;*
4. *Members of ISO Central Secretariat and IEC Central Office*

Initial members include: Australia, Canada, China, France, Germany, Italy, Korea, Netherlands, UK, US, SC 24, SC 27, SC 36, SC 41, SC 42, JTC 1/WG 11, JTC 1/WG 12

Convenor: Sha Wei

Duration: Through the November 2020 JTC 1 Plenary
JTC 1 instructs its Committee Manager to issue a call for additional participation.
The AG is instructed to submit an interim report by 23 September 2019 in time for consideration at the November 2019 JTC 1 Plenary as well as subsequent reports to the May 2020 JTC 1 Plenary and the November 2020 JTC 1 Plenary.

During the ISO/TC 184/SC 4 Plenary held in Toulouse, France from 12 – 17 May, the following resolution was approved:

SC 4 acknowledges the report of JTC 1 N14262 and Resolution 20 and nominates Sangkeun Yoo to be a liaison to the digital twin advisory group in accordance with membership category 2. SC 4 recommends that TC 184 also nominate a representative to the advisory group.

7. Recommendations

At this point in the process, the recommendations noted below are based on observations made during the creation of this report. From the introduction, Digital Twin is a concept that is currently going through a rapid and significant series of adjustments and learnings as more stakeholders become engaged in the discussion. The following are observations from the team and recommendations on next steps.

1. The group recommends that this Ad Hoc remain through the next meeting of ISO/TC 184 in order to further refine the concepts started in this report and continue to serve

as an engagement mechanism to other groups (like JTC 1) that are forming in other standards bodies.
2. The group concurs with the recommendation from ISO/TC 184/SC 4 that ISO/TC 184 join the JTC 1 Advisory Group on Digital Twin and nominate a representative from the TC to serve in that capacity.
3. The group recommends that this Ad Hoc report be submitted to JWG 21 at its meeting in July with the intent to socialize the definition.
4. The group recommends that this report be shared with the ISO/TMB SMCC with the intent to socialize the definition in dialogue with IEC/SyC SM toward a common recommendation on the definition to both ISO/TMB and IEC/SMB.
5. The group recommends that JWG 21 examine the relationship of the Asset Administration Shell to the requirements for Digital Twins and form a task force on this topic.

To that end, the draft report was shared at the most recent ISO/TC 184 Plenary meeting held in Gaithersburg, USA 25 – 26 June, 2019 and the following resolution was agreed to:

Resolution 648 (Gaithersburg 13) – Digital Twin ad-hoc committee
TC 184 decides to adopt the recommendations from the Digital twin adhoc committee as resolutions :
- TC 184 decides that the ad-hoc group remains active through the next meeting of ISO/TC 184 in order to further refine the concepts started in this report and continue to serve as an engagement mechanism to other groups (like JTC 1) that are forming in other standards bodies.
- TC 184 nominates Kenneth Swope as TC 184's liaison representative in the JTC 1 advisory group on Digital Twin.
- TC 184 decides that the ad-hoc group report be submitted to JWG 21 at its meeting in July with the intent to socialize the definition.
- TC 184 decides that the ad-hoc group report be shared with the ISO/TMBG/SMCC with the intent to socialize the definition in dialogue with IEC/SyC SM towards a common recommendation on the definition to both ISO/TMB and IEC/SMB.
- TC 184 invites JWG 21 to examine the relationship of the Asset Administration Shell to the requirements for Digital Twins and form a task force on this topic.

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[1] Federal Ministry for Economic Affairs and Energy (BMWi) Public Relations, The Structure of the Administration Shell: TRILATERAL PERSPECTIVES from France, Italy, and Germany.
[2] Grieves, M., 2014. Digital Twin: Manufacturing excellence through virtual factory replication. White paper, pp.1-7.
[3] ISO/IEC/JTC1, Technology Trend Report on Digital Twin.
[4] Stark, R., Kind, S. and Neumeyer, S., 2017. Innovations in digital modelling for next generation manufacturing system design. CIRP Annals, 66(1), pp.169-172.
[5] Centre for Digital Built Britain, 2018. The Gemini Principles.
[6] Future SC4 Architecture PWI N2632, ISO/TC 184/SC 4: Industrial Data.
[7] Digital Twin Landscape, 2019, Matthew West, Information Junction Ltd.

[8] Resolutions Adopted at the Meeting of ISO/IEC JTC 1, 6-10 May 2019 in Lahaina, Maui, Hawaii, ISO/IEC JTC 1 N14262

Annex A: Standards in scope for Digital Twin

The following table is an extract of base standards from each SC in TC 184. Note that many standards contain multiple parts. For the purpose of brevity, only the base standard title and number is identified.

Committee	Standard number	Standard title
ISO/TC 184	ISO/TS 18101-1	Oil and gas interoperability -- Part 1: Overview and fundamental principles
ISO/TC 184	ISO/TR 23087	The Big Picture of standards
ISO/TC 184/SC 1	ISO 14649	Industrial automation systems and integration -- Physical device control -- Data model for computerized numerical controllers
ISO/TC 184/SC 1	ISO 22093	Industrial automation systems and integration -- Physical device control -- Dimensional Measuring Interface Standard (DMIS)
ISO/TC 184/SC 1	ISO 23570	Industrial automation systems and integration - Distributed installation in industrial applications
ISO/TC 184/SC 1	ISO 2806	Industrial automation systems - Numerical control of machines - Vocabulary
ISO/TC 184/SC 1	ISO 2972	Numerical control of machines -- Symbols
ISO/TC 184/SC 1	ISO 3592	Industrial automation systems -- Numerical control of machines -- NC processor output -- File structure and language format
ISO/TC 184/SC 1	ISO 4342	Numerical control of machines -- NC processor input -- Basic part program reference language
ISO/TC 184/SC 1	ISO 4343	Industrial automation systems -- Numerical control of machines -- NC processor output -- Post processor commands
ISO/TC 184/SC 1	ISO 6983	Automation systems and integration -- Numerical control of machines -- Program format and definitions of address words
ISO/TC 184/SC 1	ISO 841	Industrial automation systems and integration -- Numerical control of machines -- Coordinate system and motion nomenclature
ISO/TC 184/SC 1	ISO/TR 6132	Industrial automation systems -- Numerical control of machines -- Operational command and data format
ISO/TC 184/SC 4	ISO 10303	Industrial automation systems and integration -- Product data representation and exchange
ISO/TC 184/SC 4	ISO 13584	Industrial automation systems and integration -- Parts library
ISO/TC 184/SC 4	ISO 14306	Industrial automation systems and integration -- JT file format specification for 3D visualization
ISO/TC 184/SC 4	ISO 15531	Industrial automation systems and integration -- Industrial manufacturing management data
ISO/TC 184/SC 4	ISO 15926	Industrial automation systems and integration -- Integration of life-cycle data for process plants including oil and gas production facilities
ISO/TC 184/SC 4	ISO 16739	Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries
ISO/TC 184/SC 4	ISO 18629	Industrial automation systems and integration -- Process specification language
ISO/TC 184/SC 4	ISO 18828	Industrial automation systems and integration -- Standardized procedures for production systems engineering
ISO/TC 184/SC 4	ISO 22745	Industrial automation systems and integration -- Open technical dictionaries and their application to master data
ISO/TC 184/SC 4	ISO 8000	ISO 8000 Data quality
ISO/TC 184/SC 4	ISO/PAS 17506	Industrial automation systems and integration -- COLLADA digital asset schema specification for 3D visualization of industrial data
ISO/TC 184/SC 4	ISO/TS 18876	Industrial automation systems and integration -- Integration of industrial data for exchange, access and sharing
ISO/TC 184/SC 4	ISO/TS 29002	Industrial automation systems and integration -- Exchange of characteristic data

Committee	Standard number	Standard title
ISO/TC 184/SC 5	ISO 11354	Advanced automation technologies and their applications -- Requirements for establishing manufacturing enterprise process interoperability
ISO/TC 184/SC 5	ISO 13281	Industrial automation systems – Manufacturing Automation Programming Environment (MAP LE) – Functional architecture
ISO/TC 184/SC 5	ISO 14258	Industrial automation systems -- Concepts and rules for enterprise models
ISO/TC 184/SC 5	ISO 15704	Industrial automation systems – Requirements for enterprise-reference architectures and methodologies
ISO/TC 184/SC 5	ISO 15745	Industrial automation systems and integration -- Open systems application integration framework
ISO/TC 184/SC 5	ISO 15746	Automation systems and integration -- Integration of advanced process control and optimization capabilities for manufacturing systems
ISO/TC 184/SC 5	ISO 16100	Industrial automation systems and integration – Manufacturing software capability profiling for interoperability
ISO/TC 184/SC 5	ISO 18435	Industrial automation systems and integration -- Diagnostics, capability assessment and maintenance applications integration
ISO/TC 184/SC 5	ISO 18436	Condition monitoring and diagnostics of machines -- Requirements for qualification and assessment of personnel
ISO/TC 184/SC 5	ISO 19439	Enterprise integration -- Framework for enterprise modelling
ISO/TC 184/SC 5	ISO 19440	Enterprise integration -- Constructs for enterprise modelling
ISO/TC 184/SC 5	ISO 20140	Automation systems and integration -- Evaluating energy efficiency and other factors of manufacturing systems that influence the environment
ISO/TC 184/SC 5	ISO 20242	Industrial automation systems and integration – Service interface for testing applications
ISO/TC 184/SC 5	ISO 22400	Automation systems and integration - Key performance indicators (KPIs) for manufacturing operations management
ISO/TC 184/SC 5	ISO 9506	Industrial automation systems -- Manufacturing Message Specification
ISO/TC 184/SC 5	ISO/PAS 19450	Automation systems and integration -- Object-Process Methodology
ISO/TC 184/SC 5	ISO/TR 10314	Industrial automation – Shop floor production
ISO/TC 184/SC 5	ISO/TR 11065	Industrial automation glossary
ISO/TC 184/SC 5	ISO/TR 13283	Industrial automation -- Time-critical communications architectures -- User requirements and network management for time-critical communications systems
ISO/TC 184/SC 5	ISO/TR 18161	Automation systems and integration – Applications integration approach using information exchange requirements modelling and software capability profiling