DIGITAL INDUSTRIES SOFTWARE

Defining the digital twin

Using digital threads to enable the Department of Defense Digital Engineering ecosystem

Executive summary
From a Siemens Digital Industries Software perspective, there is only one digital twin. It is the digital representation of a physical entity used to support decisions and provide insights needed to achieve desired outcomes. The digital twin provides a mechanism to collect and integrate the data needed to feed the system to support the creation of real products. When fully mature, the virtual representation can be connected to the physical entity to provide closed-loop feedback.

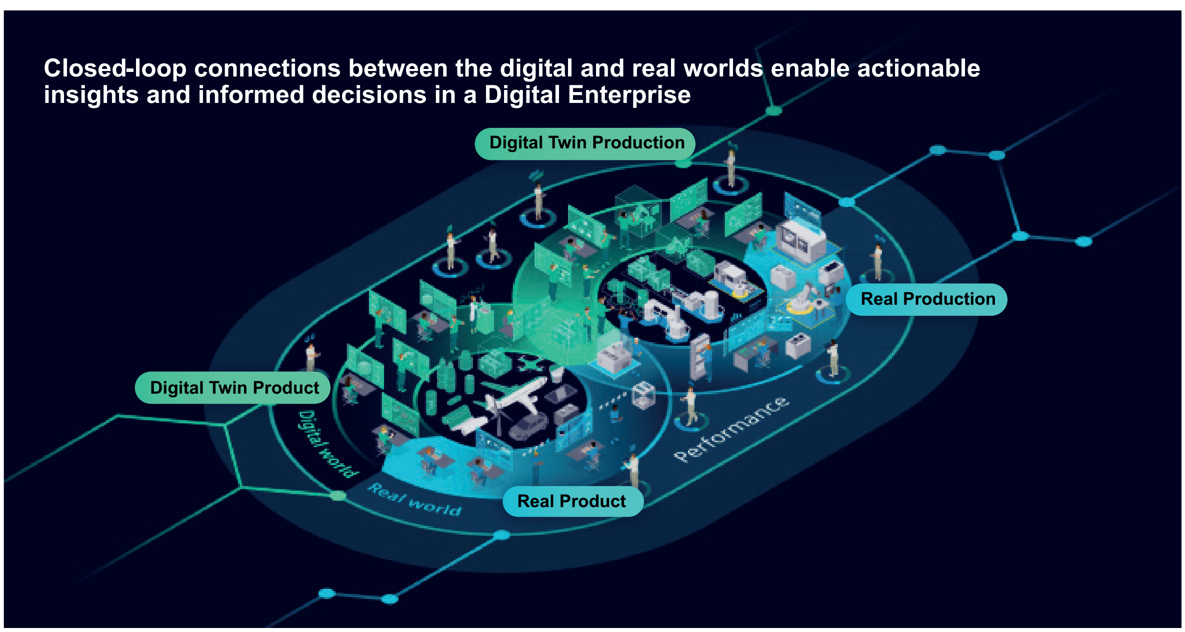
A digital thread is a collection of narrative steps and scenarios that can provide a complete view of the product lifecycle, from design and engineering to production and maintenance, supporting decisions by individual stakeholders in the Department of Defense (DoD) Digital Engineering ecosystem. By capturing data throughout the product lifecycle, a digital thread can ensure that changes to the digital twin are documented and traced back to systems models and requirements.

Introduction

This white paper covers the questions about the roles digital engineering plays in defining the types of the digital twin. It details Siemens perspectives on the digital twin and digital threads that represent the perspectives of major stakeholders in developing and supporting decisions they need to make to reach desired outcomes.

Roles of digital engineering in defining types of a digital twin

To bring the comprehensive digital twin to life, Siemens offers the Siemens Xcelerator business platform of software, hardware and services. Using Siemens Xcelerator unlocks a powerful industrial network and blurs the boundaries between traditional standalone engineering domains, such as electrical, mechanical and software. It also allows greater collaboration across product and production lifecycle stages. Its solutions get streamlined and delivered both on premises and via software as a service (SaaS) cloud solutions in the Siemens ecosystem, which includes our partners.



> "As the product evolves (parts, subassemblies replaced/overhauled) in the field, how do we capture evolution of the configurations of digital twins and have the traceability to systems models/requirements via as-built/as-delivered structures?"
>
> AIAA Digital Engineering Interoperability Committee

It is important to understand not only the benefits of a product digital twin, but also the production digital twin. Having an accurate twin of your production processes and equipment can help speed up new product introductions (NPIs), identify areas of improvement and move to a predictive maintenance approach to improve your overall uptime and efficiency.

From a Siemens perspective, there is only one digital twin. It is the digital representation of a physical entity, and when fully mature the virtual representation can be connected with the real entity to provide closed-loop feedback and insights needed to achieve desired outcomes.

On a practical level, we talk about the product digital twin and the production digital twin. One represents a collection of digital surrogate models dealing with the end item, and the other deals with a collection of digital surrogate models dealing with the production facilities used to produce the end item. They are both actors that can and do interact with each other during the manufacturing process.

In the bigger picture, there is also a digital facilities twin, and it represents the buildings and campus that houses the digital production twin. Siemens Smart Infrastructure provides Siemens Xcelerator to manage building technologies that surround the digital production twin, giving it power, water, heating ventilation and air conditioning (HVAC) and physical security.

On a grander scale there needs to be a digital system twin, one that virtually represents the environment in which the digital product twin operates. Siemens is working on a project with a partner that has built a "synthetic moon" that will provide the environment on the moon, including terrain features, sunlight/radiation exposure, localized temperatures and pressures that the digital product twin will be able to interact with in the metaverse for Defense Advanced Research Projects Agency (DARPA) and its partners.

Siemens Digital Industries Software focuses on the digital product twin and the digital production twin aspects but works with other parts of Siemens Industries that provide factory automation, motion control and industry services that can form the basis of the real production.

That includes concepts like the executable digital twin (xDT), which is a portion of the digital product twin deployed on an edge device connected to the real product. Unlike the traditional digital twin, which is primarily used for monitoring and analysis, an executable digital twin is an active, dynamic model that can respond to inputs, simulate scenarios and make decisions autonomously or with human intervention. In simple terms, the xDT is the digital twin on a chip. The xDT uses data from a (relatively) small number of sensors embedded in the physical product to perform real-time simulations using reduced-order models (ROMs). From those small numbers of sensors, it can predict the physical state at any point on the object (even in places where it would be impossible to place sensors).

Siemens is working with NVidia and Amazon Web Services (AWS) to make this kind of digital twin available as actors in the industrial metaverse, leveraging platforms like the NVidia Omniverse and AWS TwinMaker. Leveraging the Universal Scene Description (USD), components of the digital product twin or digital production twin can be added to an environment that represents behaviors and attributes of both other actors in the scene and the behaviors of the scene itself.

Capturing the evolution of configurations of the digital twin for parts and assemblies that are being replaced or overhauled can be a complex process, but there are several strategies that can be used to ensure traceability to systems models and requirements.

A robust change management process can help ensure that changes to the digital twin are properly documented and tracked. This process should include procedures for documenting changes, updating the digital twin and verifying the changes have been properly implemented.

A configuration management system can help manage the digital twin by capturing the configuration of the product at each stage of its lifecycle. This can help ensure that changes are properly documented, and the digital twin accurately reflects the current state of the product.

It ensures the digital twin is integrated with other systems to provide a comprehensive view of the entire product lifecycle. This can help make sure that changes are properly documented, and the digital twin accurately reflects the current state of the product.

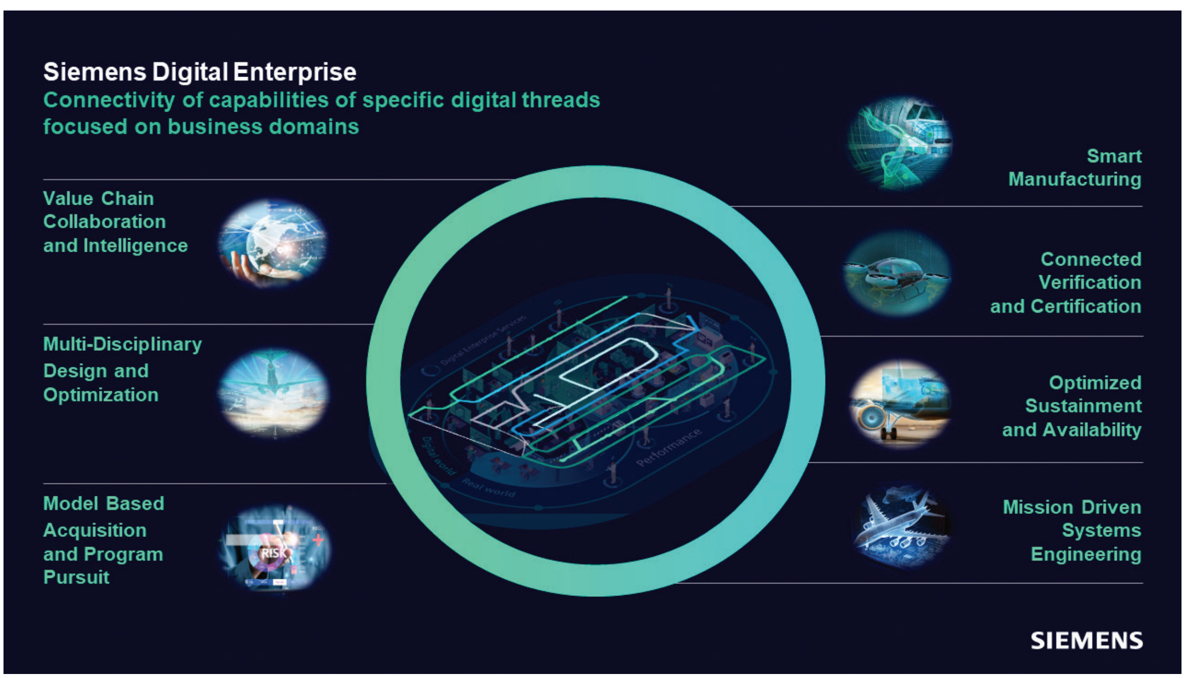
The aerospace and defense digital threads provide a prescriptive business framework to develop and mature a complete view of the product lifecycle from the perspective of individual stakeholders. From design and engineering to production and maintenance, it supports decisions by individual stakeholders in the digital engineering ecosystem. From the perspective of the system itself, Siemens talks about a "Digital Thread for Defense," integrating the perspectives of all of the stakeholders throughout the lifecycle, providing an overarching view of the system lifecycle that should be familiar to resources working in the defense acquisition, technology and logistics (AT&L) lifecycle as described by Department of Defense Instructions (DoDI) 5000.02, "Operation of the Adaptive Acquisition Framework," DoDI 5000.97 "Digital Engineering" and DoDI 5000.88 "Engineering of Defense Systems."

Digital threads for aerospace and defense

The evolution of the digital twin is driven by the need of stakeholders to make decisions to ensure outcomes. But these stakeholders have different perspectives and responsibilities, so Siemens has developed a set of digital threads that define the processes and scenarios needed to evolve the digital twin over time to support their decisions and outcomes. The digital threads for aerospace and defense predate but align closely with the organization taxonomy of digital threads developed during workshops at AIAA SciTech 2024 by the United States Air Force (USAF) Digital Material Management (DMM) team.

The model-based acquisition and program pursuit digital thread embodies the key elements from the program management perspective. It supports program pursuit, program planning and successful program execution. It provides a foundation for incorporating digital twin perspectives from other stakeholder perspectives into program level decisions and outcomes.

The mission-driven system engineering digital thread is critical for developing a system driven by end user needs and aligned with business priorities. The mission in mission-driven systems engineering is the virtual simulation of a notional system in a representative environment, where the end user describes the environment and desired attributes. These attributes are aligned with the business priority of increased reuse, alignment with existing products, market segments, personnel and skill sets. The mission is also used during verification, validation and while reviewing closed-loop product insights to ensure consistency in both the developed product and its digital twin.



The multidisciplinary design and optimization digital thread embodies the perspective of the chief engineer. It leverages architectures driven from the mission-driven system engineering thread to enable multidisciplinary design, the only solution with integrated mechanical, electrical, electronics and software design to support cross-domain optimization of the product digital twin.

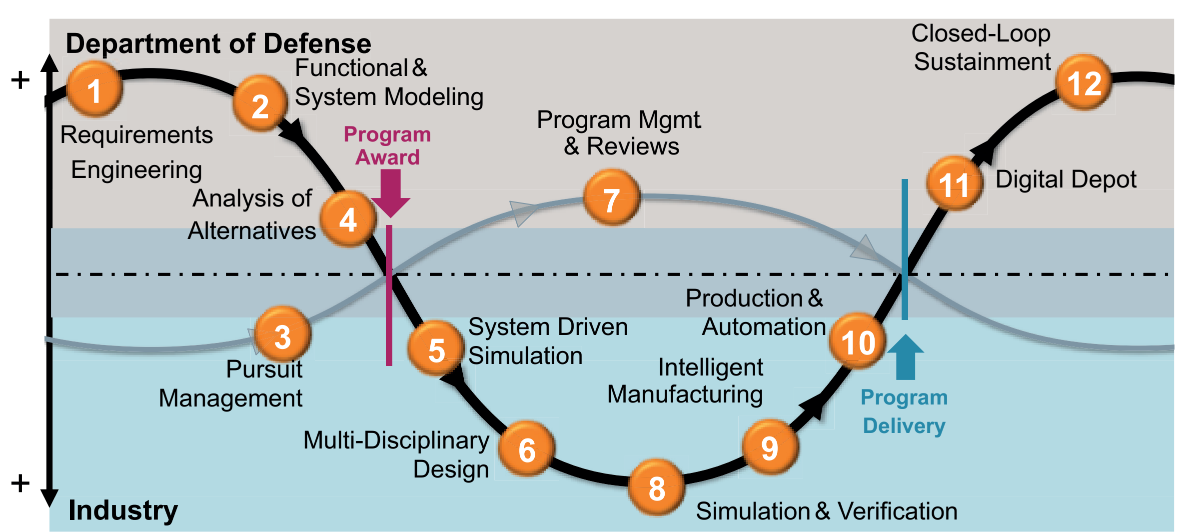
The smart manufacturing digital thread represents the perspective of the production manager, building a digital twin that can be leveraged on the shop floor. You can create a digital twin of the production process to simulate, identify and address issues well before the design is released. This digital twin extends to the physical world, where process and quality plans can be seamlessly used to support shop floor execution and closed-loop feedback enables continuous improvement of product and process. This enables you to deliver quality products on time while meeting cost targets.

The connected verification and certification digital thread provides the perspective of the test manager to proactively and accurately plan the digital twin to execute large scale complex verification and certification programs in full coordination with all other stakeholders. This will aid collaboration with civilian or DoD certification authorities (CA) and foster trust in verification processes, shortening overall certification program length.

The optimized sustainment and availability digital thread provides the perspective of the product support manager. It evolves the digital twin to define, simulate, identify and address issues when planning for service well before the design is released. The validated service plan can be leveraged to support service execution in the field. All the information is captured in the digital twin of each asset, allowing you to perform maintenance when needed, reducing sustainment cost and increasing asset availability.

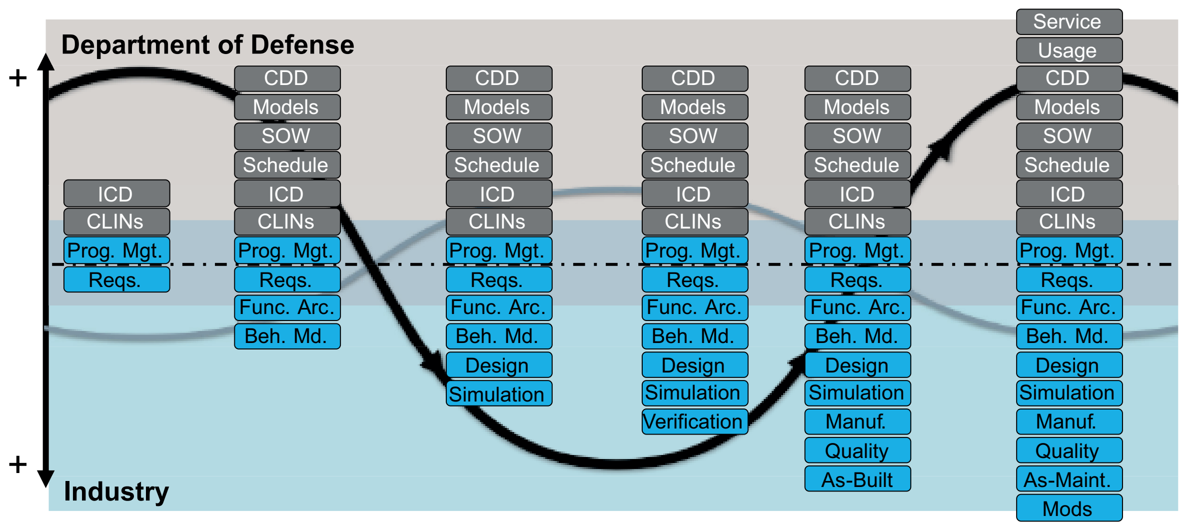
The value chain intelligence and integration digital thread represents the perspective of the supply chain. It allows other stakeholders to incorporate supply chain capabilities and constraints into the design, test, manufacturing and support process early on. It enables building a model-based supply chain that uses enterprise resource planning (ERP) data and market intelligence to select parts with lower risk and drive quality throughout the supply chain.

Digital engineering is just a subset of the capabilities of the entire Siemens Xcelerator portfolio and what Siemens calls the Digital Thread for Defense. It is a big picture view, a level above the viewpoint



of individual stakeholders, and represents the maturity the digital twin will need to have at different points throughout the lifecycle of defense systems. We are confident we will be able create data structures, models and workflows that will enable management of the entire DoD digital engineering process domain. The figure below shows the entirety of our Digital Thread for Defense, a high-level view of the entire digital thread needed to support a defense program.

In more practical terms, there are many different artifacts, analyses, studies, bill-of-materials (BOM), computer-aided design (CAD) models, etc. that make up a digital thread, much of which is not, and may never be, digitalized. The figure below shows the exponential growth of the data which need to be maintained in a digitalized engineering environment:



Conclusion

The potential applications for a digital twin depend on what stage of the product lifecycle it is being used to model. Generally, the digital twin has three versions: product, production and performance. The combination and integration of the three as they evolve together is known as the digital thread. The term "thread" is used because it is woven into (and brings together data from) all stages of the product and production lifecycles.

Product digital twin
The product digital twin replicates physical products in a digital form. They are used in product design, testing and simulation. The product digital twin helps engineers and designers analyze how a product will perform in different conditions, enabling them to optimize its design and functionality before physical production begins.

Process digital twin
The process digital twin simulates and analyzes the behavior of physical processes or systems. They are used to monitor, control and optimize the operations of complex systems such as manufacturing plants, supply chains and energy grids. The process digital twin enables organizations to visualize, simulate and analyze processes in real time, facilitating better decision-making and performance optimization.

System digital twin
The system digital twin replicates entire systems or ecosystems in a digital environment. They integrate the digital twin of products, processes and other components to comprehensively simulate the behavior of complex systems. The system digital twin is used to model and analyze large-scale systems such as smart cities, transportation networks and industrial complexes.

Note
This series of papers was written by Siemens to support a request for vendor perspectives by the AIAA Digital Engineering Integration Committee (DEIC). The final AIAA Paper, "Digital thread and twin integration: Defining the problem space – OEM and vendor perspective on gaps" delves into the challenges and gaps identified by the industry while integrating the digital thread with digital twin. The AIAA paper builds on the past digital thread and twin position and realization papers published during 2021-22 and will be presented at AIAA SciTech 2025.

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For additional numbers, click here.

Siemens Digital Industries Software helps organizations of all sizes digitally transform using software, hardware and services from the Siemens Xcelerator business platform. Siemens' software and the comprehensive digital twin enable companies to optimize their design, engineering and manufacturing processes to turn today's ideas into the sustainable products of the future. From chips to entire systems, from product to process, across all industries, Siemens Digital Industries Software – Accelerating transformation.

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