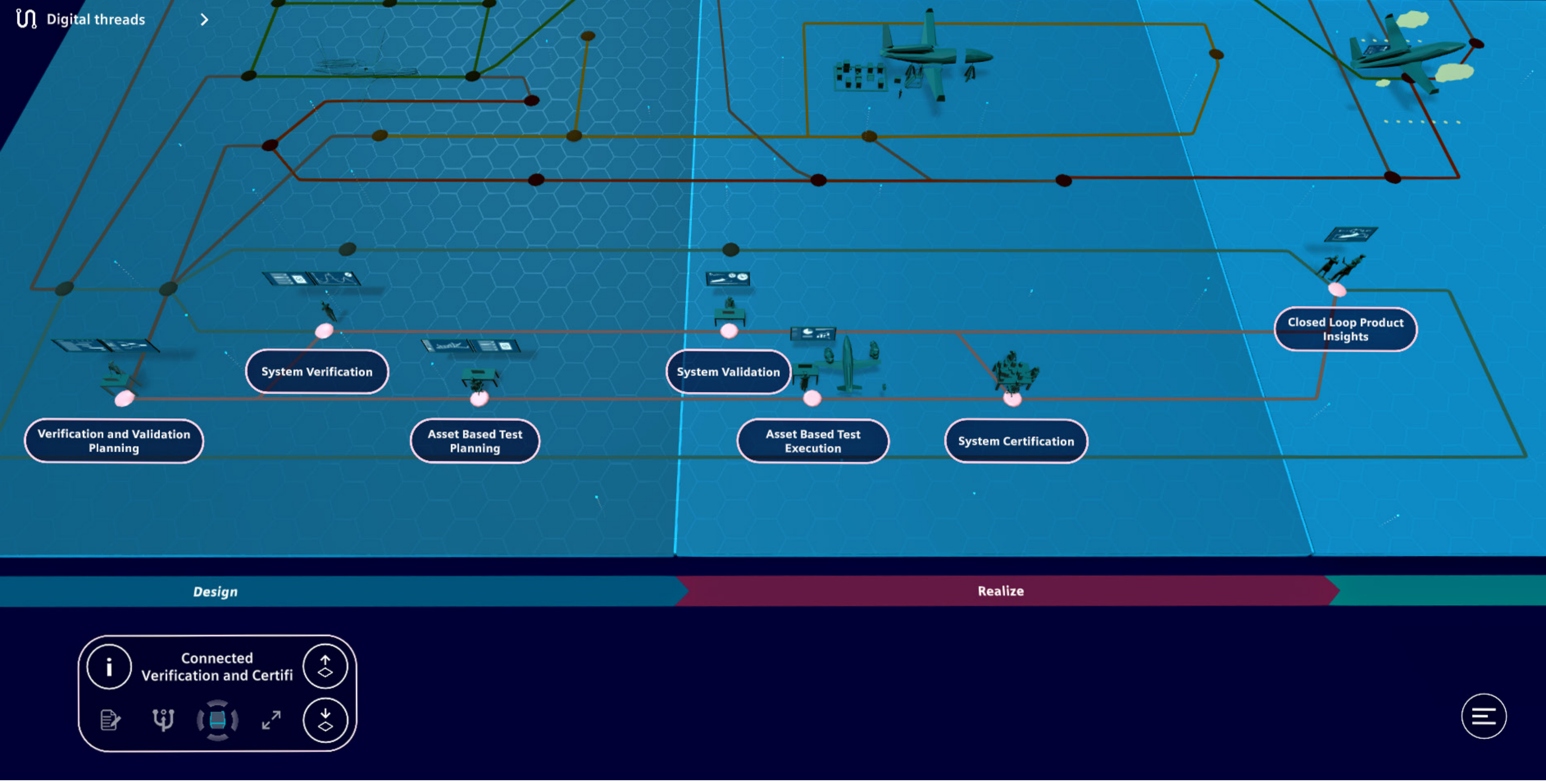



DIGITAL INDUSTRIES SOFTWARE

# Requirements connected verification and certification

Understanding vendor perspectives about integrating a digital thread and digital twin


**Executive summary**

For manufacturers of aerospace products, certification and traceability are everything. From the complete spacecraft, aircraft, powerplants and avionics systems to individual line replaceable units (LRUs), detail parts and raw materials, certification and traceability are critically important. The reason the National Air Transportation System is a treasure and economic powerhouse is because it is safe and reliable. This is due to federal regulations that require exhaustive verification and certification of those safety and reliability requirements. These requirements ensure every product's soundness of design and aspect of its manufacture, operation and support throughout its lifecycle and eventual decommissioning.

# Introduction

Accelerating the certification process requires a holistic approach, where all product data is interconnected and traceable. Tracking iterative design changes, simulations, analyses and testing becomes not just a requirement but a crucial element for program success. By seamlessly integrating simulation and virtual testing into your project plan, original equipment manufacturers (OEMs) and supply chain stakeholders can synchronize certification testing and documentation with the ongoing iteration of parts and systems. This establishes a continuous link between analysis and virtual/physical testing, reducing reliance on physical parts for demonstration and proof of compliance. By encompassing internal requirements throughout operation, service and support, companies can achieve a comprehensive, fully traceable and auditable chain of data. With a streamlined verification management and certification process, manufacturers can produce and demonstrate compliance for new advanced products, achieving certification faster and more efficiently than ever before.

# Requirements management

**Modeling digital twin requirements**

Modeling the requirements of a digital twin involves identifying the final product's key features and capabilities to meet the mission and goals of the product. The digital twin should accurately represent the behavior and performance of the physical system the company is designing.

The first step for modeling digital twin requirements is to identify the physical system needed to achieve the desired performance and resulting outcomes. This involves identifying the key physical components and subsystems, as well as the inputs, outputs and control mechanisms used to operate the system. Comprehensively documenting the requirements and their attributes is a best practice, which you can accomplish using a robust requirements management tool.

After identifying the physical system, it is important to define the scope of the digital twin. This involves defining the level of detail the digital twin requires, as well as the key features and capabilities it should have. To accurately represent the physical system's behavior, you need to feed the digital twin data from the physical system and the environment in which it will operate/perform. This involves identifying the data sources that will be used, such as existing models, sensors, historic, empirical and other sources of data.

After identifying the data sources, you need to define the modeling approach. This involves using physics-based models, data-driven models or a combination of both. You should select the modeling approach based on the level of detail you require for the digital twin and the availability of data. Further, combinations of analysis, visualization and simulation may be appropriate. For example, a static loading analysis may yield deflections of a physical structure, and you can feed those deflections into a separate kinematic model to evaluate complex aeroelastic effects such as potential interferences of highly stressed interfaces and other effects due to the deflection of the structure.

Depending on the physical system's complexity and the modeling approach used, the digital twin may require significant computational resources. You should determine the computational requirements in advance to ensure you can develop and operate the digital twin efficiently.

Finally, you need to identify the key features and capabilities of the digital twin. This involves defining the visualization tools used to display the behavior of the digital twin and the analytics tools used to analyze the data it generates. The key features and capabilities should align with the requirements of the stakeholders who will use the digital twin. An example of this is an evaluation of a physical space by maintainers to ensure proper room for their physical access, including clearances for any necessary tools, and the removal and reinstallation of parts/components.

By following these steps, you can model the requirements of the digital twin in a structured and systematic way. This improves accuracy, reduces operating, fabrication, assembly and maintenance costs, enhances customer satisfaction and supports successfully implementing a digital twin in various industries.

### Capturing system behavior requirements

Capturing requirements in a system's behavior involves identifying the specific behaviors it should exhibit to meet stakeholder and marketplace needs. The first step is to identify the impacted stakeholders. This includes end-users, customers, operators, maintainers, etc.

After identifying the stakeholders, you need to define the objectives of the system. This involves identifying the key performance indicators (KPIs) used to measure the system's success and the desired outcomes for each stakeholder.

Once you have defined the objectives, you need to identify the specific behaviors the system should exhibit. This involves defining the inputs, outputs and control mechanisms used to operate the system, as well as the expected responses to specific inputs or events. Specific parameters aid the engineers in making the critical tradeoffs necessary to optimize a given design.

After identifying specific behaviors (for example, speed, range, fuel efficiency, etc.), you need to define the acceptance criteria for each one. This involves specifying the range of acceptable values for each KPI, as well as the conditions and/or limitations the system should respond to in a specific way.

Finally, you need to document the system’s behavior requirements clearly and concisely. This involves using diagrams, flowcharts or other visual aids to help stakeholders understand the requirements and limitations. These data objects will ideally be related, released and managed with respect to their controlling single sources of truth. For example, the system, subsystem or detail part models and drawing objects should be managed in a robust project lifecycle management (PLM) system.

### Visualization, security realms, data rate and sensor needs

Visualization is an important aspect of a digital twin as it enables stakeholders to understand and interact with the behavior of the modeled physical system. When capturing requirements for visualization, it is important to consider the level of detail required, the types of data that need to be visualized and the tools and technologies that will be used to display the data.

Security is another important aspect of a digital twin, as it often relies on sensitive data and can connect to critical infrastructure. When capturing security requirements, it is important to consider the types of threats the digital twin may face, the security mechanisms that will be used to protect the system and the access controls that will be put in place to ensure only authorized users can access the digital twin.

A digital twin can rely on real-time data from sensors and other sources to accurately represent the modeled physical system’s behavior. When capturing requirements for data rate, it is important to consider the frequency the data needs to be collected, the volume of data that will be generated and the bandwidth required to transmit the data to the digital twin.

Sensors are an important source of data for the digital twin. When capturing requirements for sensor needs, it is important to consider sensor type, its accuracy and precision needs, placement and maintenance requirements. You can use virtual sensors to establish the right sensor types, locations and data acquisition needs early in the design process.

# Verification and validation

### Using a digital twin for validation and verification

The digital twin is a virtual representation of physical entities and includes powerful tools for modeling and simulating complex systems. To ensure their reliability and accuracy, validation, verification and uncertainty qualification (VVUQ) are essential. Validation compares the outputs of a digital twin to real-world data, ensuring it accurately simulates the physical system. This involves comparing model predictions with experimental or observational data. Verification ensures the computational model of the digital twin aligns with the developer's intended design. It checks for implementation and other errors and confirms the algorithms correctly solve the specified equations.

Uncertainty qualification (UQ) is crucial for understanding the inherent uncertainties in a digital twin model. UQ involves identifying, quantifying and reducing uncertainties in model inputs, parameters and predictions. This helps assess the confidence level of the outputs of the digital twin and supports informed decision-making. Together, VVUQ ensures the digital twin is robust, reliable and capable of providing accurate and actionable insights, which is crucial for applying it in various fields.

### VVUQ challenges for a digital twin

Building a trustworthy digital twin requires incorporating uncertainty quantification into all components, from data assimilation to optimal decisions. This is challenging for large, complex systems with spatiotemporal dynamics and extensive parameter or decision spaces. Further, uncertainties can evolve over time, adding complexity.

Common challenges include:

- Model discrepancies: Mismatches between the digital twin and the physical system
- Unresolved scales: The inability to capture all relevant scales of the system
- Surrogate modeling: Using simplified models that may introduce uncertainties
- Extrapolation: Making predictions beyond the range of available data
- Physical counterpart uncertainties: Changes in sensors, data collection equipment or the physical system's state
- Information transfer: Challenges in passing information between the physical and virtual realms
- Parameter uncertainty: Uncertainty in model parameters
- Ill-posed or indeterminate inverse problems: Difficulties in determining unique solutions
- Human-in-the-loop: Uncertainty introduced by human interaction

These challenges can be categorized into two main types:

1. Aleatory uncertainty: Inherent randomness, noise or overlapping feature distribution in data. This is irreducible even with more training data.

2. Epistemic uncertainty: Uncertainty due to limited data, lack of knowledge or model simplifications. This can be reduced with more information or data.

By addressing these challenges and effectively implementing VVUQ, organizations can build a reliable and valuable digital twin for various applications.

You can use a digital twin to test and simulate the behavior of physical systems under various conditions. This can support verification and validation (V&V) by enabling engineers to identify potential issues and optimize the system's performance before it is built. Additionally, by using the digital twin of the physical product as the single source of truth (SSoT), you can maintain comprehensive, robust and disciplined configuration management. This is critical to ensure you analyze and test the right configuration(s) of the system, subsystems and individual components as a design evolves. Further, the test articles often need specific configuration for testing. For example, a static wing bending load test could include the shear attach fitting at the wing to fuselage join. Additionally, it may be included in a separate fuselage static test rig. With a digital twin, engineers can account for every part and configure their tests accordingly. Using a digital twin enables the specific configuration of the test article to account for defining and configuring test setups, instrumentation, calibrations and specific equipment to ensure the most accurate and relevant test results possible.

A digital twin can be used to validate the accuracy of models that represent the physical system's behavior. This can support V&V by ensuring the models accurately represent the physical system's behavior and can be used to make accurate predictions. Leveraging a digital twin allows engineers to use multiple boundary conditions, combinations of gross weights, center of gravity (CG) locations and configurations (gear up and flaps up, gear down and flaps up, gear up and flaps down, etc.). This ensures you define and understand the critical conditions for each required safety and performance requirement, as well as any necessary operating limitations and that the sensitivity of those critical conditions as internal configurations change. For example, you can use a digital twin to enhance your understanding of how performance and other characteristics change when consuming fuel.

With a digital twin, you can monitor the behavior of physical systems in real time and predict if it requires maintenance. This can support V&V by ensuring the physical system is operating within expected parameters and reducing the risk of unexpected failures. Although engineers can anticipate the performance and response of their design in various operating environments, operating configurations, failure modes and their effects, realistically, until that system is in service, there remain possible unknowns. Enabling a closed-loop feedback system from physical operations can inform the product digital twin by analyzing and comparing the physical environment or performance and reliability to the design requirements, analysis and tests.

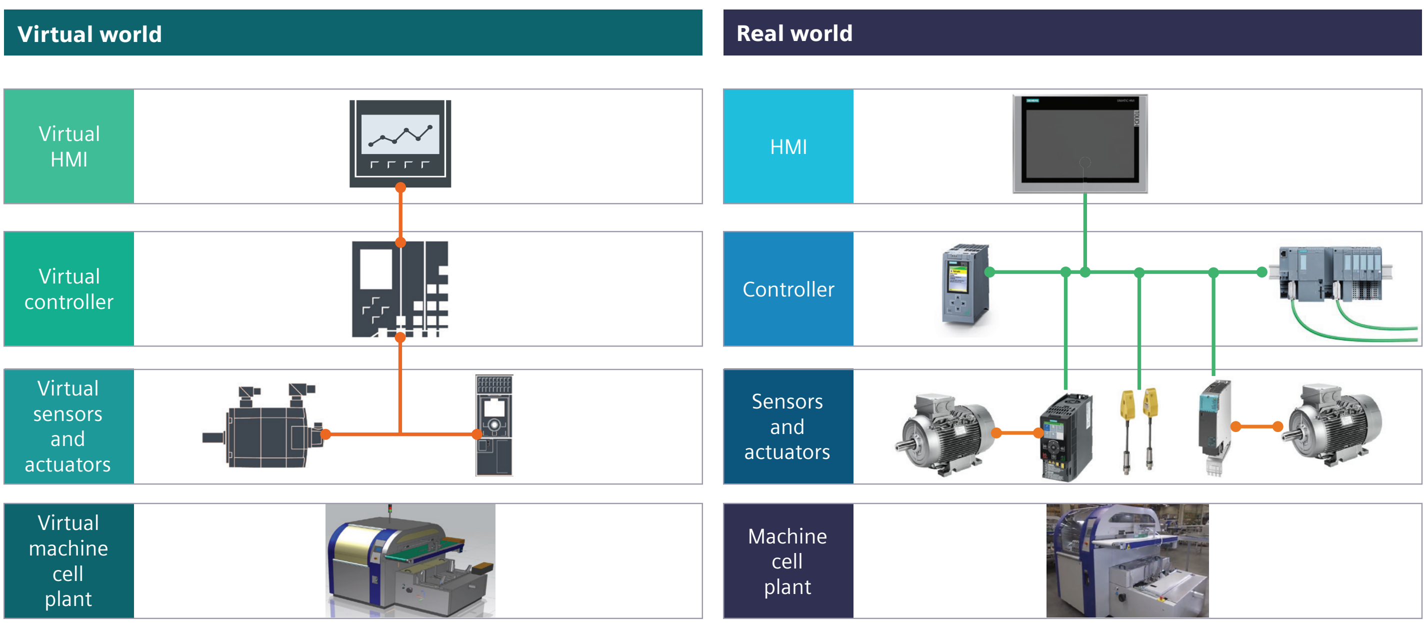
A digital twin can generate enormous amounts of data that can be used to analyze the physical system's behavior. This can support V&V by enabling engineers to identify patterns and anomalies in the data that may indicate issues with the physical system.

Overall, using a digital twin can support the V&V process by providing a virtual representation of the physical system, the manufacturing process to create it and its performance. Leveraging a digital twin is an efficient way to analyze, test, validate and optimize the system's behavior. This can support focused, prioritized continual design improvement resulting in improved performance, reduced maintenance and overall cost of ownership/operation, maximizing availability and enhancing customer satisfaction.

### Virtual commissioning with a digital twin

When you use Siemens Digital Industries Software's Plant Simulation in the Tecnomatix® portfolio, which is part of the Siemens Xcelerator business platform of software, hardware and services, for virtual commissioning, the test and plant optimization processes are entirely virtual, using a fully integrated virtual controller as part of the production digital twin. This way, you can test all relevant automation functions safely and efficiently before commissioning. Most importantly, you can correct almost all development and functional problems before physically commissioning the product. By importing existing planning and engineering data and libraries with ready-to-use components, you can leverage Plant Simulation Virtual Commissioning for faster and more economical commissioning. This means you can deliver your project and power up the system on time or ahead of time.

With Plant Simulation Virtual Commissioning, you can greatly expand the normal scope of testing. Simulation can take place in parallel with the engineering process. Identifying errors and performing more extensive tests on automation solutions earlier improves the quality of engineering. Virtual commissioning is also an efficient aid during project definition and helps operators and partners meet customer specifications. This avoids costly reworking, retooling and other conflicts that previously would come as surprises.



Operator training systems are more important as a means of ensuring employees have the necessary skills and efficiency the company requires. Virtual commissioning makes it possible to perform tests without input from machines, equipment or facility personnel. This eliminates the inherent risks of local commissioning. With Plant Simulation Virtual Commissioning, you can create realistic training environments for plant operators with less time and effort. In the training environment, plant operators also work using the original operating images and automation programs. In other words, the only difference is they are running a virtual plant rather than a physical one. Using the integrated virtual controller lets you create the training environment without requiring lots of space or hardware. This means plant operators can begin training using Plant Simulation Virtual Commissioning before the company completes the physical plant. Leveraging the operator training system also makes it possible to provide regular training for plant operators, even in situations that do not occur with the physical plant regularly. It also gives new employees an easy and competent introduction into their working environment.

The digital twin can play a crucial role in virtual commissioning, which is the process of testing and validating the behavior of a system before the company builds or installs it. Operators can use a digital twin to:

- Simulate and test the physical system's behavior in a virtual environment. This can support virtual commissioning by enabling engineers to identify potential issues and optimize system performance before building it
- Optimize the behavior of physical systems by testing various configurations and identifying the best system settings. This can support virtual commissioning by ensuring the physical system is designed to operate at peak performance
- Validate the accuracy of models to represent the behavior of physical systems. This can support virtual commissioning by ensuring the models accurately represent the physical system's behavior and can be used to make accurate predictions
- Achieve remote commissioning, which involves commissioning a physical system from a remote location using a virtual representation. This can support virtual commissioning by reducing the need for engineers to be physically present on site, which can save time and reduce costs

The production digital twin can support virtual commissioning by providing a virtual representation of the physical system for testing, validating and optimizing system behavior before building or installing it. This can improve performance, reduce maintenance costs and enhance customer satisfaction, as well as support successfully implementing a digital twin in various industries.

# Certification

**Enabling product certification with a digital twin**

Using a digital twin can help with product certification in several ways. First, it provides a virtual representation of the physical product, allowing engineers to simulate and test its behavior and performance before building or installing it. This helps identify any potential issues and optimizes the product's performance. Additionally, the digital twin can be used to validate the accuracy of models to represent the product's behavior, ensuring they accurately reflect the physical product. These can be used for accurate predictions.

Additionally, if you require physical testing, you can use the digital twin to reduce technical and program risks by virtually testing beforehand. You can also leverage the digital twin to assist with testing the product's compliance to regulatory standards and industry guidelines. By evaluating every requirement and defining means of compliance, it ensures the product meets all necessary regulations and certifications. Further, the digital twin can be used to optimize the product's performance by testing various configurations and identifying the best settings. This helps you design the product to operate at its peak performance and ensures every critical condition and function are evaluated and documented for compliance. Remote testing is also possible with the digital twin, reducing the need for engineers to be physically present at the testing site and saving time and costs.

Overall, the product digital twin supports certification by providing a virtual representation that facilitates testing, validation and optimization, improving quality, reducing costs and enhancing customer satisfaction.

# Conclusion

The complexity of certifying, manufacturing, operating, supporting and maintaining aerospace products is evident. These programs are perhaps the most complex endeavors the government and industry face today. To manage the lifecycle processes necessary to support these programs, a robust, comprehensive database system is necessary to ensure you do not miss any details. The Siemens Xcelerator business platform is one of the world's most capable systems, designed to manage the digital twin and digital threads the government and industry need to ensure the safety, performance and reliability of these highly engineered complex systems.

**Note**

This white paper covers a set of related questions about requirements management, verification, validation and certification detailed in the quotes above. When Siemens talks about the digital threads for aerospace and defense, one of those threads is called "connected verification and certification." This paper does not cover all the details of that digital thread but addresses the specific AIAA questions that relate directly to these topics.

Siemens has authored this series of papers to support a request on vendor perspectives by the AIAA Digital Engineering Integration Committee (DEIC). The final AIAA white 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 a 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.

**Siemens Digital Industries Software**

Americas: 1 800 498 5351

EMEA: 00 800 70002222

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