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Ingenuity for life

Siemens Digital Industries Software

Maturing simulation and test capabilities for the digital twin

Executive summary

The boundaries between design and the product life after delivery are disappearing. This trend will transform product development from a process that delivers discrete generations into a continuous process that keeps track of individual products and constantly updates them until end of life. Companies must embrace the digital twin concept to remain competitive, and embrace leading-edge simulation and testing tools that exploit the digital twin.

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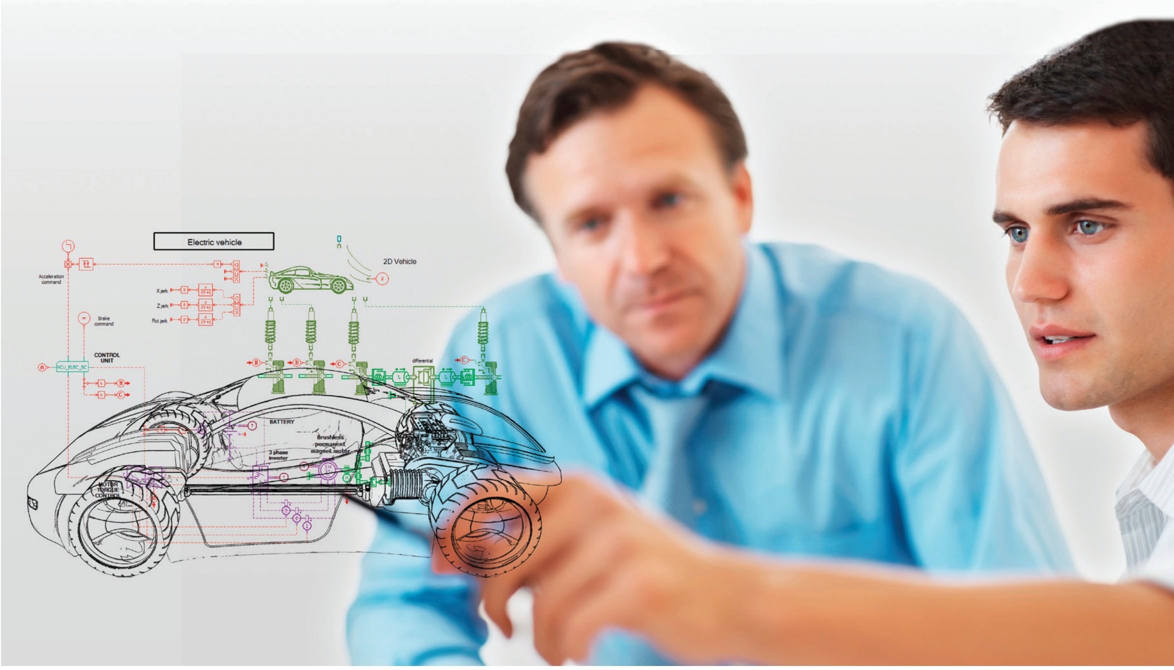
Product complexity and the risk to businesses

Within the last few years, a convergence of various technologies is transforming engineered products in many different industries. What are these trends? You know them well if you are involved in any capacity with bringing new products to market that require significant engineering development – cars, planes, machinery and medical devices to name just a few. Consider the potential of new materials to transform the relation between form and function, new manufacturing processes that make it possible to produce shapes that were never before possible, the integration of software and electronics to improve performance, and the possibilities that Internet of Things (IoT) data can afford to satisfy customer needs in new ways. Apart from these, there are the trends for mass personalization, greater demand for fuel efficiency, and more regulations including the mandate to reduce emissions.

The net result of all these is an increase in complexity of both products and the processes that are used to engineer them. The challenges resulting from this increased complexity are significant. Longstanding companies with rich histories of innovation in one area may struggle to leverage their experience in emerging fields. Will a company that knows how to build mechanical locks lead the way to internet-connected devices that can be locked and unlocked from a smartphone? Or will they watch helplessly as new companies take away market share? How will they integrate their experience on the mechanical side with newly acquired knowledge on sensors, electrical actuators and internet connectivity to bring new products to market faster than upstarts? If a company is not thinking of these types of questions, it will surely be left behind in just a few short years.

There is a way forward and it requires a mindset to embrace the concept of digital twins. But before we outline the way forward, let us examine some of the trends and challenges in a little more detail.



Industry trends

Performance, fuel economy and emissions

One trend that has existed for a while relates to the continuous demand for increased product performance and improved fuel economy. Together with safety and reliability, these are without doubt the most function-critical design aspects for many industries, as they directly result in measurable economic added value for customers, or even determine, in some industries, whether missions are possible.

In addition, public interests play a role. The pressure we put on our planet is huge. Global concerns such as the scarcity of fossil fuels and global warming have led to international agreements on CO_2 emissions, and to strict legislation. Governments have committed to numbers and percentages, and are counting on the industries to come up with innovations to make these happen.

New materials

Aviation companies are in the forefront of research activities in materials. The aerospace industry has naturally always been the number one laboratory for new lightweight materials, such as composites. Very famous commonplace examples were certainly the Boeing 787 Dreamliner and the Airbus A350, the first commercial aircraft with major structural elements made of composites. There are many other examples.

New manufacturing processes

Additive manufacturing is opening up new possibilities for weight reduction, but also poses new challenges for design and simulation, including the creation and optimization of organic shapes, dealing with lattice structures, and handling thermomechanical effects of the manufacturing process itself. As this exciting area evolves, the industrialization of additive manufacturing will lead to new possibilities of manufacturing lightweight parts at scale, but also in usage of mixed materials to impact function, embedding sensors into components and more.

Integration of electronics and software with mechanical

Products today deliver their functions through the integration of mechanics, electronics and software. For example, aircraft engines, wind turbines and automotive braking systems all require significant engineering with electronics, software and controls to optimize multiphysical behavior.

New digital technologies will take the application of such systems to the next level. New and more precise sensor types, more powerful microprocessors, better algorithms, data mining capabilities and more will be real industry game-changers.

Mass personalization

Increasing demand for personalization is impacting many industries, driven partly by globalization where people in different countries or regions may have different product preferences. Companies are seeking to meet these demands by introducing more software-based options and by adopting platform strategies on which variants can be offered. The engineering challenge they face is to ensure that each variant functions as intended. How do companies test 10,000 different variants of a product? How can they prove that they verified performance?

New business models and familiar engineering challenges

Recent innovations are also creating new business models that threaten to disrupt traditional value chains. In a sharing economy, a product sale may no longer be the primary source of revenue, but rather the beginning of a long-term relationship where value is derived through on-going product enhancements and maintenance driven by usage data insights. And then there is the opportunity created with vast amounts of sensor data. Products today have the ability to monitor and measure usage and deliver all this data to the owner, but also to the manufacturer and suppliers who engineered and built the product. How can this data be used with other performance data to deliver new insights?

There are familiar engineering challenges to consider as well. For example, automobile manufacturers anticipate autonomous vehicles needing to last three to four times as long in terms of total miles driven as compared to traditional vehicles. This clearly has an implication on durability engineering.

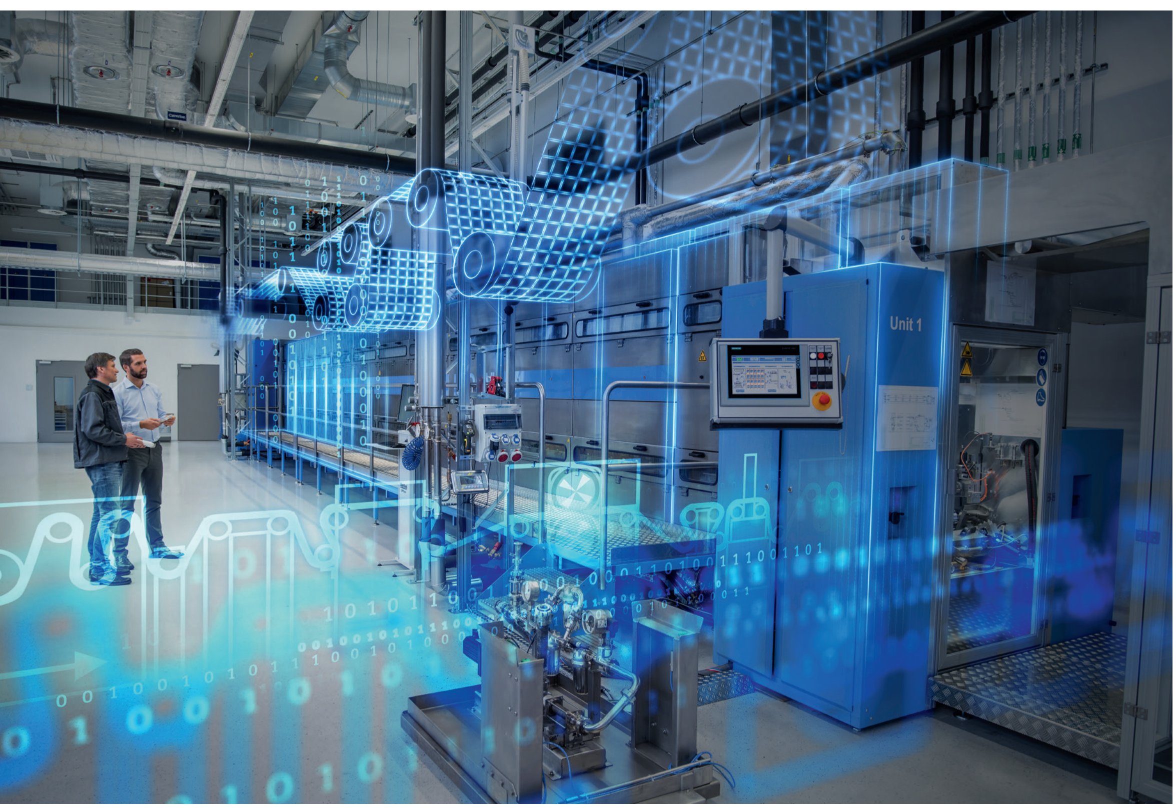
System of systems and IoT

Increasingly, products are comprised of multiple systems, often built by different suppliers, which need to interact with each other to deliver the desired performance. Consider vehicle systems that not only need to communicate with each other but with other vehicles, the road, traffic signals, etc.

Collaboration is needed to optimize performance of not just individual products, but also the overall behavior of these complex systems. This requires a model-based approach to product development.

The one constant

There is, of course, one constant: the ever-increasing pressure on time, quality and cost. Dealing with these new trends take more time, requires more quality overall and, of course, costs more money. Working with new materials is harder, requires more testing, and raises new questions about reliability. Designing a system that works with other systems created by other companies or organizations is harder. How does an organization deal with this?



Challenging the way engineering is done

The implications of these trends are that manufacturers face many more unknowns in the engineering process, which leads to longer lead times and greater risks that they will not achieve the product and business objectives. Companies that fail to recognize and react to these changes risk losing business and market share. So, how can companies respond to these new challenges?

What if a company could adopt new practices and tools to give it a competitive edge? Today engineering data and models are scattered in different silos. While most companies have activities and groups that are performing tests, generating benchmark data, running 1D simulations, and performing computer-aided engineering (CAE) work, there is no ability to easily draw conclusions across the silos. The test engineers may not even be aware that a 1D simulation being performed. The CAE department may not have access to the latest benchmark data. What if they can use all the data across multiple engineering activities and convert this into meaningful insights that can drive product decisions faster than the competition?

When all these different silos of models and data are linked together, there is the possibility of more realistic models that can be used to predict behavior. Data from one model may be used as input to a different model that is built later in the process. The models themselves can mature over time. And the models can even be kept up-to-date with actual usage data obtained through IoT-enabled products. And a layer for analytics that leverages data from a variety of sources can help uncover trends and insights earlier.

The digital twin concept

An important way to address challenges of complex system development is by building a set of highly accurate models that help predict product behavior during all lifecycle phases. These models, which are called "digital twins," come in multiple scales and instances for various applications, integrate multiple physical aspects, contain the best available physical descriptions and mirror the life of the real product and its production process.

The concept of a digital twin is applicable across various lifecycle stages of a product or system.

- From the ideation phase, with a digital twin of the product that helps define/improve designs and analyze performance
- To the realization phase, with a digital twin of the manufacturing process
- To the utilization phase, with a digital twin of the product in service and through retirement

When companies integrate all of these digital twins together, they have access to a holistic digital twin which becomes the backbone of their product development – capable of delivering greater insight, reducing development cycle time, improving efficiency and increasing market agility.

Origins of the digital twin

The concept of using physical models that mimic behavior of actual products is not new. For example, NASA's Apollo program used identical space vehicles so that one of the vehicles could be used to test out procedures on earth while the other was in space. The concept of a "mirrored spaces model" was introduced in executive courses on product lifecycle management at the University of Michigan in 2002. Perhaps the first use of the phrase "digital twin" is seen in 2011/2012 in reports by NASA and the U.S. Air Force Research Laboratory (AFRL).[1]

In the NASA report, the term was defined as follows: "A digital twin is an integrated multiphysics, multiscale simulation of a vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin."

The AFRL report also has some powerful concepts including

- When a physical aircraft is delivered, a digital model of the aircraft – specific to that tail number, including deviations from the nominal design – will be delivered as well.
- The digital model will be flown virtually through the same flight profiles as recorded for the actual aircraft.
- The modeling results will be compared to sensor readings recorded at critical locations to update/calibrate/validate the model.
- As unanticipated damage is found, it will be added to the digital model so that the model continually reflects the current state of the actual aircraft.

The digital twin tracks information on all parameters that define how each individual product behaves over its entire useful life, including initial design and further refinement, manufacturing-related deviations or anomalies, modifications, uncertainties, updates as well as sensor data from the vehicle's on-board integrated vehicle health management (IVHM) system, maintenance history and all available historical and fleet data obtained through data and text mining.

More than just a simulation model

The engineering performance digital twin is more than a simulation model. Instead it is a "living entity" that is extended, completed and updated throughout the asset's lifecycle, further enriched with data obtained during the physical asset's operation.

Additionally, three things are needed for the digital twin to be realized as described by the NASA report referenced earlier:

- A realistic simulation model (the digital twin) that can predict performance
- A specific physical asset or family of assets which is the real equivalent to the digital twin
- Information flow between the physical asset and the digital twin so that the latter is dynamic and evolves over the life of the asset

The availability of digital twins can help predict performance of complex products and systems throughout the product's lifecycle. Consider an industrial product being used in Finland. A simulation model by itself would assume nominal behavior and nominal loads and therefore would not be able to accurately predict performance for the specific asset in question. With a digital twin approach, the situation is different. Sensors on the product may provide noise signatures. This data in conjunction with a digital twin that incorporates knowledge of the as-used (versus as-designed or even as-built) condition of the product, other sensors that provide current and historical loads, temperature fluctuations, etc. can then be used to anticipate and predict a vibration problem within the next 10,000 duty cycles.

So, while the simulation model is essential to the creation of a digital twin, it is not sufficient to have only a static simulation model. It must evolve over time and the evolution must be captured at all stages.

As such the digital twin begins its existence even before its physical counterpart exists and continues to evolve and support the next generation of the physical asset long after the current generation ceases to exist.

The digital thread

The concept of the digital thread is related to the concept of the digital twin. The digital thread captures information on all the data, models, processes and resources from requirements to design and engineering to usage for the digital twin. And it does this across all the functional areas and for all stakeholders. Thus where the digital twin can be considered as the virtual entity that can predict performance, the digital thread tracks the evolution of the digital twin and helps to keep it up-to-date and current.

Benefits and challenges of a digital twin approach

Reducing risk and improving performance

The digital twin includes all the required information to continuously forecast the product's performance and health, the remaining useful life, or for some applications, even the probability of mission success. It can also predict system response to safety-critical events and uncover previously unknown issues before they become critical by comparing predicted and actual responses.

Ultimately, if available at the peak of its abilities, systems on board the digital twin could be capable of mitigating damage or degradation. They could activate self-healing mechanisms or recommend changes in a mission profile to decrease loadings, and thereby increase both the life span and the probability of mission success. Or they could suggest updates of intelligent systems to improve product performance and reduce fuel consumption.

Reducing product and operational cost

Traditionally the approach has been to assume appropriately severe conditions during design and subsequent usage tracking as well as rather large safety factors to account for the manufacturing process. Such an approach is very conservative and leads to products that may be heavier than they should be and require more frequent inspections than necessary.

Thanks to the precision of its models, using a digital twin can reduce design tolerances, while taking into account manufacturing uncertainties and stochastic variability of material properties and of product use. This will result in a huge cost reduction in every respect, including the use of materials during production, fuel consumption as well as a better plan for inspection and maintenance.

Reducing development time and production cost

By providing an integrated view of the product's various physical and behavioral aspects, the digital twin will allow simultaneous balancing of all functional performance requirements throughout the entire development cycle, from early concept to detailed engineering and final validation. Digital twins can also provide earlier and greater insights on how systems interact and their potential failure modes. This will avoid several test-and-repair loops and greatly reduce the time that is required to have a product ready for production.

Increasing innovation

The systematic use of digital twins to fully explore the design space, to integrate IoT data, and to better understand the interactions of different systems will generate tremendous new insights for product development teams. These insights will in turn drive faster innovation as new ideas emerge that had never been considered before.

Challenges to develop the digital twin

If well-conceived, the digital twin should bring clear advantages to product development, manufacturing and after-delivery service. But the extent to which the concept is deployed still depends on what a company can or wants to do, and on the capability of technologies. For most companies, the concepts behind the digital twin as described above can be exciting but also quite daunting. A few of the challenges are keeping up to date with innovations in materials and manufacturing processes, modeling system behavior earlier, tracking the evolution of critical design parameters, understanding the impact on adjacent systems, taking advantage of IoT innovations, etc.

In the remainder of this paper, we introduce a maturity model concept that can act as a guide for organizations on where to invest on this journey towards the digital twin.

Investing for the digital twin

Initially the most compelling applications may be found in assets whose performance is critical but where monitoring or servicing is either very expensive or practically not feasible. Such examples may be found in off-shore and wind energy applications, satellites and mining, among others. However, companies across the manufacturing spectrum will find the digital twin approach to be useful, even necessary, as innovators begin to use digital twins to offer superior service, performance and responsiveness. It is imperative for companies to start their journey towards the implementation of a digital twin strategy now rather than wait for some future event to trigger investment, by which time it may be too late.

In order to help companies with a measured approach to the adoption of digital twins in product development, we have created a simple model with three main axes representing different areas for any company to focus on to improve core capabilities related to digital twin adoption – realism, continuity, and exploration.

Realism

The first focus area for maturity is realism of the digital twin. To address increasingly complex systems and technologies, it is critical that companies have a realistic representation of their product to give confidence in their designs and ensure that design decisions are correct. Improved confidence in both simulation and test data can reduce the need for over-design, reduce end-of-cycle physical testing and reduce the number of field failures. All this leads to faster time to market and significant cost savings. In addition to that, having confidence and trust in simulation and test processes is also critical to make real-time decisions based on feedback from the digital twin.

There are many ways companies can mature along the realism axis. For instance, they can consider

- The coverage of physics and disciplines – single, multiple, coupled. Higher levels of maturity imply the use of more sophisticated models that yield results that are closer to reality by combining disciplines and physics. For example, there can be a computational fluid dynamics (CFD) model, a structural dynamics model, a thermodynamic model, a stress analysis model and fatigue cracking model. And those can all be very accurate for their specific use. But in reality, these physics are coupled and that needs to be reflected in the digital twin.
- The scope of the model – component, system, system of systems (or complete product). As a company matures its use of digital twin technology, one can expect it to be able to assess performance of systems or the entire product.

- The information it is based on – simulation or test only, hybrid simulation and test, actual usage. Simulation and test are used to augment each approach. For example, tests can be used to correlate simulation models and achieve greater accuracy. Simulation can in turn augment test results by providing performance metrics in areas where testing alone cannot. And virtual sensors can augment the information collected from real sensors. At the highest levels of maturity, companies utilize actual usage data and historical data and feed it into the digital twin for more accurate simulations of real-world behavior under a myriad of conditions.
- The speed with which the digital twin can yield information – slower than real time, real time, faster than real time. One can imagine that very fast simulation-based digital twins may even be embedded into the physical asset to improve performance in real time.

Continuity

Second, to support the digital twin, it is critical that performance engineering processes are not isolated and disconnected from the rest of the organization or the PLM process. Companies need a digital thread that connects people, projects, models and data to efficiently tackle the innovation of these very complex problems. If companies are able to reduce barriers and enable enterprise collaboration, they not only increase their process efficiency, but also get a more holistic view to make the right decisions with all stakeholders across the organization and are able to close the loop between requirements, design and verification over the complete engineering cycle.

The digital twin concept requires a strong connection between all models that are used during the entire product lifecycle. Only a true digital thread can, for example, allow using the same 3D solid models from design in manufacturing for numerically controlled programming, tracking parameter changes for individual products during manufacturing and use, or enabling products in the field to provide feedback to design and engineering teams.

In practice, this means that an enormous amount of data needs to be preserved for decades, must be updated constantly and needs to be accessible for a large number of different user profiles, located around the globe and often even spread over various companies. To create and maintain a digital twin, manufacturers will need to deploy large data storage infrastructure, powered by a very robust data management system.

There are various ways companies can mature with respect to continuity:

- How models and data are managed – ad-hoc, archived, managed and traceable. At low levels of maturity, engineers are left to their own methods for storing models and data. Higher levels of maturity demand strategic use of a data management backbone for all product knowledge.
- How models and data are linked – independent, shared and cascaded, closed-loop with links to requirements and product usage. While managing data and models is a start, for a digital twin strategy to be effective, companies must ensure that relationships and links between requirements, models, results, and data are also maintained and are traceable. And a platform for IoT is needed to connect usage data to the digital twin.
- How processes are managed – documented, managed and automated. When maturity levels are low, companies may find that each engineer is performing a simulation using a different modeling process which eventually yields results that are different. Maturity along this axis means well documented and managed processes and automation of processes that eliminates most sources of error.

Exploration

Third, having realistic and integrated processes and models today is not enough. Companies must be able to deploy them so that they bring the necessary insight to make design decisions and do it quickly. A key value of digital performance analysis is that it allows for quick and cost-effective evaluations of design changes. To get the most benefit from simulation tools, companies must intelligently explore the design space to quickly understand design drivers and tradeoffs, and discover better designs. This of course also requires the ability to interrogate the information from these hundreds of designs to make decisions. High-quality analytics as well as visualization are also critical to make simulation useable and accessible.

Here are some maturity characteristics to consider with respect to the exploration axis:

- How exploration is done – ad-hoc, automated, intelligent. At low maturity, engineers may use a single-point simulation to validate an existing design or troubleshoot design flaws in a reactive manner. Automated exploration utilizes simulation in a more predictive way. For example, simulations are used to look at the performance of a handful of designs early in the development process in place of physical tests, but the value is primarily in reducing engineering time and cost by replacing physical prototypes and tests. At the highest maturity levels, simulation is used with design exploration to intelligently explore the design space and with data analytics with the aim of realizing better products.
- How results are consumed – interpreted by experts, automated reports, interactive with rich visualization. Insights derived from exploration are most useful for supporting design decisions. Often the decision makers do not have expertise in the simulation or testing methods and tools. Companies can mature their capabilities in exploration by moving from numerical results that only an expert can interpret, to standard reports with charts and graphics, to interactive models and immersive experiences for visualizing the results of simulations.
- What the analytics is based on – sensor data, sensor data with other performance data, including historical data. Data techniques that integrate the data from various sources such as virtual sensors, real sensors, subjective evaluations, historical data, etc. require more sophisticated analytics and indicate higher levels of maturity.

Productivity

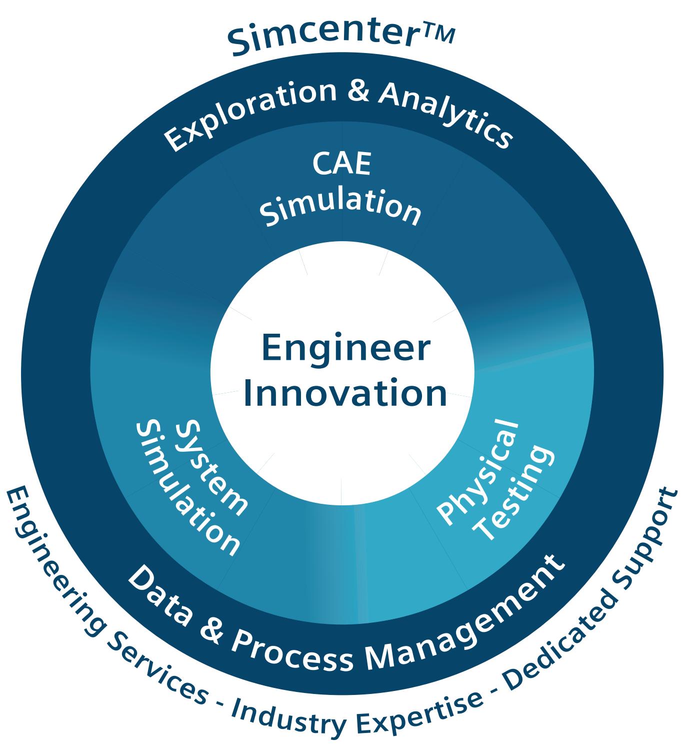
And of course, the backbone for all of this needs to be a set of streamlined and automated workflows, consistent interfaces and efficient processes that reduce engineering time and allow engineers to spend their time where it matters: innovating.

A digital twin must deliver insights in time to influence decisions – decisions about service or predictive maintenance, timing of upgrades to improve performance, or decisions taken during development phases. The organization has a number of things to consider here: how to push the use of system models early so that the right architectures are selected; ensuring a consistent user experience across domains and enabling models and data to be re-used; streamlining data flows between applications; automating workflows to achieve speed as well as standardization; ensuring efficiency in testing and augmenting test data with simulation data to enable faster and deeper insights; investing in the right computing resources to enable rapid evaluations of hundreds of design variants; and enabling large, complex models to be manipulated quickly and visualized easily.

When companies transform their performance engineering processes in this way, they are able to engineer innovation. Ultimately what this means is that they increase their market agility to bring better, more innovative products to market faster at a lower cost.

Introducing the Simcenter portfolio for the digital twin

Siemens Digital Industries Software recognized the product complexity trends more than a decade ago and embarked on a journey to build the strongest portfolio in the industry in support of building digital twins. Our belief for the need to adopt this new approach for performance engineering in support of the holistic digital twin has led us to the creation of the Simcenter™ portfolio. Simcenter delivers best-in-class CAE simulation, system simulation and testing solutions, as well as solutions for design exploration and data management. The portfolio consists of longstanding solutions and brands from various legacy companies including UGS, SDRC, LMS, CD-adapco, Mentor Graphics, a Siemens business and others. The portfolio continues to evolve and grow through internal R&D, acquisitions and solution integration. Our intent is nothing less than delivering to our customers the capabilities and support needed to build the most robust and accurate digital twins to engineer innovation.



Delivering confidence

Each Simcenter solution is architected to be best-in-class for specific domains. Simcenter brings a wide range of physics and disciplines together under one umbrella, giving the ability to capture not only all the complexities of different types of physics but also enabling multiphysics simulation to study phenomena across physics domains spanning structural analysis, computational fluid dynamics, thermal simulation, electromagnetics, multibody dynamics, and supported by system simulation, design exploration, simulation data management and more.

Through its multi-fidelity solutions (including system simulation, CAE simulation and as well as efficient testing solutions), Simcenter covers all stages of development, from concept to detailed engineering to physical testing.

Siemens invests heavily to ensure that Simcenter solutions work together and embed the necessary technologies to address specific industry challenges. This results in dedicated capabilities for energy management, electrification, autonomous operation and more, impacting multiple industries including automotive, aerospace, machinery, marine, energy, medical and electronics.

Facilitating collaboration

Companies always have a variety of tools deployed for product development – whether for legacy reasons or to benefit from specific strengths of some tools. With Simcenter, companies are not limited to the solutions in the portfolio; it is open to enable seamless coexistence with other tools across the company. This includes, for example, accepting CAD from any source, writing out to a variety of solvers, managing data from any application, and openness in terms of support for industry standards and formats.

Within Simcenter, the solutions can leverage the Internet of Things to integrate sensor-based data with high-fidelity physics-based simulations, allowing manufacturers to build and maintain digital twins of their products and to keep them in sync with the physical product in use. This is of crucial importance to making more useful and realistic predictions of product performance that will enable these products to adapt to changing usage conditions, extend their useful life and accommodate system degradation.

Engineering teams today are generating huge amounts of data and in order to be effective, this data needs to be managed and tracked. Simcenter solutions work with Teamcenter® software to help engineers manage their models and data and keep them in sync with design. Simulation data management enables our customers to capture engineering knowledge and make it available for collaboration and re-use by team members. Users can assess how changes at one level impact decisions on another level. This enables traceability and cascading of key parameters throughout the lifecycle.

Driving insight

Simcenter includes an efficient and easy-to-use intelligent design exploration framework that easily integrates with your current design and simulation tools and fully leverages your high-performance computing (HPC) infrastructure. This helps you accelerate design decisions. Links to the Siemens MindSphere platform enables high-quality data analytics leveraging data from many sources. Dedicated postprocessing and visualization capabilities enable exploring, analyzing and communicating relationships in data and broaden the comprehension of results.

Enhancing efficiency

The Simcenter portfolio offers broad deployment flexibility, that enables companies to maximize the value of hardware and fully leverage investment in simulation technologies with HPC. The portfolio is supported by engineering services and dedicated support engineers. Teams of technical experts offer a broad engineering proficiency to help companies achieve complex design goals and deploy innovative engineering processes with Simcenter. Finally, Simcenter delivers streamlined user experiences and collaborative workflows. This ensures that the portfolio is easy to use and minimizes the learning curve and your time to be operational.

Simulation and test capabilities in the Simcenter portfolio

Mechatronics system simulation

System simulation, also called 1D system simulation or mechatronics system simulation, allows scalable modeling of multi-domain systems. The full system is presented in a schematic way, by connecting validated analytical modeling blocks of electrical, hydraulic, pneumatic and mechanical subsystems (including control systems). It helps engineers predict the behavior of concept designs of complex mechatronics, either transient or steady-state.

Using the Simcenter system simulation solutions, engineers can evaluate concepts very early, even before any CAD geometry is available. During later stages, parameters can then be adapted. System simulation calculations are very efficient and therefore lend themselves to design exploration. The component are analytically defined, and have input and output ports. Causality is created by connecting inputs of a component to outputs of another one (and vice versa). Models can have various degrees of complexity, and can reach very high accuracy as they evolve.

Because of their inherent applicability to multiple physics, their scalability and their outstanding computational performance, system simulation models are excellent and versatile components of a digital twin. Some model versions may allow real-time simulation, which is particularly useful during control systems development, or later in the product lifecycle, as part of built-in predictive functionality inside the product.

Multi-discipline and multiphysics CAE simulation

CAE models can account for additional phenomena that naturally relate to 3D physics aspects, and typically become highly detailed, computationally intensive representations that are usually very application-specific. Over the last decades, various 3D CAE technologies have proved their value by speeding up development and avoiding late-stage changes.

Simcenter features the state-of-the-art for every individual application, and bundles solutions for various functional performance aspects in a common platform to facilitate multi-discipline analysis. It also captures industry knowledge and best practices in application verticals. Simcenter includes very dedicated 3D solutions such as high-end CFD, multibody dynamics, linear and nonlinear FEA, electromagnetics, acoustic and thermal solutions, fatigue crack propagation modeling, composite analysis, and much more.

Coupled 1D simulation, 3D simulation and controls engineering

As model-based systems engineering requires concurrent development of the entire multiphysical system, including controls, the processes for 1D simulation, 3D simulation, and control algorithm development must be very well aligned. To achieve this, Simcenter offers various co-simulation capabilities for model-in-the-loop (MiL), software-in-the-loop (SiL) and hardware-in-the-loop (HiL) simulations that combine various versions or scales of digital twin models in a coupled analysis.

Model-in-the-loop
Already when evaluating potential architectures, system simulation should be combined with models of control software, as control units will play a crucial role in achieving and maintaining the right balance between functional performance aspects when the product will operate. During this phase, engineers cascade down the design objectives to precise targets for subsystems and components. They use multi-domain optimization and design tradeoff techniques.

Control simulation needs to be included in this process. By combining control models with the system models in MiL simulations, potential algorithms can be validated and selected. In practice, MiL involves co-simulation between virtual controls from dedicated controller modeling software and scalable 1D models of the multi-physical system. This provides the right combination of accuracy and calculation speed for investigation of concepts and strategies, as well as controllability assessment.

Software-in-the-loop
After the conceptual control strategy has been decided, the control software should be further developed while constantly taking the overall global system functionality into consideration. The controller modeling software can generate new embedded C-code and integrate it in possible legacy C-code for further testing and refinement.

Using SiL validation on a global, full-system multi-domain model helps anticipate the conversion from floating point to fixed point after the code is integrated in the hardware, and refine gain scheduling when the code action needs to be adjusted to operating conditions. SiL is a closed-loop simulation process to virtually verify, refine and validate the controller in its operational environment, and includes detailed 1D and/or 3D simulation models.

Hardware-in-the-loop
During the final stages of controls development, when the production code is integrated in the control unit hardware, engineers further verify and validate performance using extensive and automated HiL simulation. The real control unit can be combined with a downsized version of the multi-domain global system model, running in real time. This HiL approach allows engineers to complete upfront system and software troubleshooting to limit the total testing and calibration time and cost on the actual product prototype.

During HiL simulation, engineers verify whether regulation, security and failure tests on the final product can happen without risk. They investigate interaction between several control units. And they make sure that the software is robust and provides quality functionality under every circumstance. When replacing the global system model running in real time with a more detailed version, engineers can also include pre-calibration in the process. These detailed models are usually available anyway, since controls development happens in parallel to global system development.

Combined simulation and physical testing
Working with a digital twin does not always mean replacing physical testing with simulation during product development. In many cases, final prototype testing for certification will be required. It will become even more complex and time-consuming with all the multi-physics and controls involved. Testing will continue to play a role, because lots of additional testing tasks will be required to reach the desired model realism, both during development and after delivery. To successfully create and maintain a digital twin, test and simulation engineers should collaborate and reinforce each other.

Simcenter uniquely brings together a complete series of physical testing applications and a comprehensive set of simulation solutions. This facilitates collaboration and data exchange between two traditionally very distinct engineering domains. On both sides, engineers will see many benefits. Test engineers can use simulation results to become more effective, whereas simulation engineers will have access to lots of data to validate and improve their models.

Use simulation for more efficient certification testing
As the number of parameters and their mutual interaction explodes in products that include many control systems, efficiency is key during certification testing, both in terms of instrumentation and definition of critical test cases. Simulation can help to analyze upfront which locations and parameters can be more effective to measure a certain objective. And it also allows investigation of the coupling between certain parameters, so that the number of sensors and required test conditions can be optimized.

In addition, simulation can be used as an observation tool to derive certain parameters that cannot be measured directly. Here again, a close alignment between simulation and testing activities is a must. Both 1D and 3D simulation models can give access to many parameters that cannot be directly reached with sensors. In fact, that is a huge advantage of using a digital twin for product development.

Increase realism of simulation models using test input

Modal testing has for decades been a useful method to help improve structural finite element models via correlation analysis and model updating. It greatly contributed to the success of, for example, structural dynamics, vibroacoustics and vibration fatigue simulation analyses on mechanical structures, and will continue doing so in the decades to come. Within a digital twin approach, modal testing will remain important, in particular for component validation.

In addition, the required fidelity of digital twin models calls for much more test-based validation and input. Measurements also need to be capable of improving 3D multibody and 1D multiphysics models, for example. And they have to help define realistic boundary conditions, loads and all kinds of simulation parameters. In the digital twin context, a broad range of new testing capabilities (some modal-based, some not) will become essential for success.

Create hybrid models that combine test with simulation

Test results can even replace entire components during simulation. Complex products are usually combinations of subsystems that are not necessarily concurrently developed. As the digital twin always strives for the best possible combination of accuracy and performance, it can be beneficial during various development stages to create hybrid setups that include hardware, simulation and test models. This will obviously require dedicated technologies as well as a very good alignment between simulation (both 1D and 3D) and physical testing.

Exploring the design space

Simcenter includes an environment that assists in discovering better designs, faster. It tackles these challenges by automating the analysis process, leveraging investments in computing hardware, efficiently searching for better performing solutions and providing intuitive ways to review the design performance. Even engineers with very little design optimization experience can use Simcenter capabilities to discover optimal designs – in a fraction of the time it would take to perform even a handful of manual iterations.

Maintaining a digital thread from development through usage

To fully exploit the capabilities of the digital twin once the product is out in the field, and to leverage it in applications such as activating self-healing mechanisms, proactive damage control and history-based updating of intelligent systems, all parameters that define the complete behavior should be traceable and kept in sync. This requires a very powerful data management system that spans the entire product lifecycle. Simcenter leverages the capabilities of Teamcenter and the MindSphere platform to achieve these objectives.

Teamcenter helps manufacturers share product designs, documents, analysis and testing data, bills of materials, sensor data, maintenance reports and more within their organization, and with suppliers and partners. With Teamcenter, companies can standardize workflows and effectively manage the entire lifecycle of individual products by providing all stakeholders role-specific access to synchronized information.

MindSphere delivers a wide range of device and enterprise system connectivity protocol options, industry applications, advanced analytics and an innovative development environment that utilizes both Siemens' open platform-as-a-service (PaaS) capabilities along with access to cloud services. Through these capabilities, MindSphere connects real things to the digital world and provides powerful industry applications and digital services to help drive business success.

Helping you in every step of the digital twin journey

Siemens is helping companies remove the boundaries between design and the product life after delivery. This will transform product development from a process that delivers discrete generations into a continuous process that keeps track of individual products and constantly updates them until end of life. In such a process, sensors on the real product can easily feed back information to the development team, enabling engineers to make predictions and plan updates or maintenance. They can decide to replace parts or components. Or they can use all this information as improved starting parameters or boundary conditions when working on a new project.

To further support your journey to embrace a digital twin approach, Simcenter Engineering and Consulting services help you in addressing complex engineering challenges and safeguarding the balance between technological design options and functional performance. Our engineering experts combine the required experience, skills and unique simulation approaches to support development programs.

In summary, the digital twin approach can help companies transform their product development process. Simulation and testing play a critical role in the creation of digital twins for performance engineering and it is imperative for companies to take a hard look at how they can mature their capabilities in this area.

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About Siemens Digital Industries Software

Siemens Digital Industries Software is driving transformation to enable a digital enterprise where engineering, manufacturing and electronics design meet tomorrow. Our solutions help companies of all sizes create and leverage digital twins that provide organizations with new insights, opportunities and levels of automation to drive innovation. For more information on Siemens Digital Industries Software products and services, visit siemens.com/software or follow us on LinkedIn, Twitter, Facebook and Instagram. Siemens Digital Industries Software – Where today meets tomorrow.

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