

# *Quick Insight Brief: Elements of Digital Twins and Projects Updates*

Advancement in technologies is fueling innovation in the nuclear industry. The need for more efficient and flexible power stations opened the doors for exploring new technologies like digital twins (DTs). In the previous quick insight report [1], EPRI provided a general definition of the DT technology and shared a few research activities in this area.

This quick insight report builds upon the previous one by discussing the key DT elements for successful use case deployment, identifying opportunities for improvement in the enabling technologies, defining typical DT project phases, and providing an update on EPRI's DT activities.

## **RESEARCH QUESTIONS**

The following summarizes the research questions to be discussed in this report.

- ▶ What constitutes a DT, and what is the process of building a DT for an application?
- ▶ What characteristics should be considered when evaluating use cases for potential deployment?
- ▶ How can a DT be used for real-time use cases?

## **KEY POINTS**

- ▶ There are several DT use cases for various life-cycle stages of operating nuclear power plants, and more are being identified with great potential for the nuclear industry. However, it is important to assess the DT elements for roadblocks and plan to address them early in the application.
- ▶ The process of building a DT requires coordinated efforts among stakeholders to define common expectations for the DT outcomes and the anticipated benefits.
- ▶ The complexity of DT application varies. A use case can be as simple as a descriptive 3D geometric model of a facility to a very detailed and complex simulation with many integrated features. One success path for reaching some of the more sophisticated end states is to start simple and scale up.
- ▶ It is also important to consider that a DT is not an all-encompassing platform meant to replace platforms that are best-in-class. Rather, it is a system of systems or a system of twins that leverages data from many different sources.
- ▶ DT capabilities have been around for a long time; recent developments in machine learning (ML) and artificial intelligence (AI) algorithms and continued growth in computing capability have been the recent catalyst generating renewed interest. These recent technological developments can enable data integration, processing, insights, and automation not previously possible.

### ELEMENTS OF A DT

The previous quick insight report [1] provided a general definition for a DT and discussed the relationship between the physical asset and its DT. While various industries and organizations define a DT somewhat differently, nevertheless, there are several key elements that are commonly required for a wide variety of DT applications (Figure 1):

- ▶ Monitoring devices and systems provide data feed and establish the communication between the physical asset and its DT. This includes sensors and network communication infrastructure such as wired and/or wireless gateways.
- ▶ Advanced modeling and simulation tools enable physics-based DTs. This DT element is not new to the nuclear industry, as engineers have long used simulation methods like finite element, finite difference, and computational fluid dynamics to evaluate existing power stations. However, recent advances in computing and parallel processing

are now enabling the possibility of performing high-fidelity simulations in near real-time, using live data feeds from monitoring systems to accelerate operational decision making with high quality analytical results.

- ▶ Data analytics, including stochastics, statistics, ML, and AI algorithms, enable data-driven DTs. There has been a notable advancement in AI and ML in recent years, and EPRI has been investing resources to enable more applications of data analytics.
- ▶ Data repositories are continuously updated with new telemetry from the deployed sensor instrumentation on the asset and data analytics. Repositories include data storage architectures such as digital configuration management information systems, data management policies such as for retention and rotation, and physical assets such as data center hardware or cloud storage.

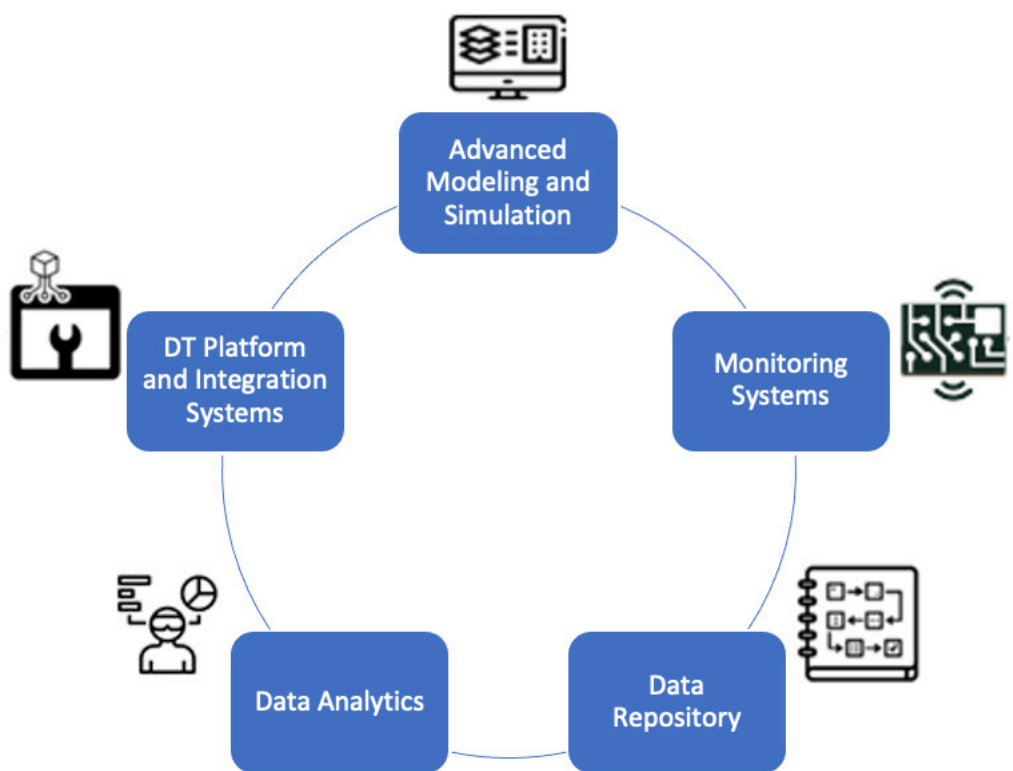


Figure 1. Elements of DTs

- ▶ DT platforms and integrator systems provide a seamless environment of data sharing and visualization of the various sources of information described above. This element can integrate data from the various disparate sensors, models, and analytics with model viewing/rendering platforms, dashboarding and data visualization tools, building information models (BIM), and geospatial information systems.

Each specific DT use case will require a unique combination and manifestation of these elements to achieve its objectives. Before implementing a given use case, it is important to identify which elements are required, specify what form they will take (for example, on-site data center vs. cloud storage), define technical requirements for each (for example, data standards, bandwidth, measurement precision), and assess them relative to several key characteristics described below.

### USE-CASE VALUE ASSESSMENT

There is a vast variety of use cases being explored and implanted across a wide range of industries from smart manufacturing, to defense, to commercial supply chain management. Yet, not all use cases offer the same potential. Some may offer substantial value yet require elements and features for which technology is not yet commercially available. Others may be straightforward to implement with off-the-shelf products yet offer relatively little return relative to the initial investment. To support EPRI members in evaluating, comparing, and prioritizing potential use cases, and to assess future potential DT-related research activities, EPRI has identified the following key characteristics of use cases and DT elements. These characteristics and corresponding questions can be used as qualitative dimensions on which to assess and prioritize potential use cases.

- ▶ **Technology readiness:** Are the necessary hardware and software tools and components readily available, or is additional research and development needed before the use case can be implemented?
- ▶ **Cost:** What costs can be expected for procuring and deploying the various elements of DTs? EPRI's research has gathered rough-order-of-magnitude cost data for various DT elements and their components.
- ▶ **Utility/value:** What kinds of benefits can be expected from implementing the various use cases?
- ▶ **Scalability:** How flexible is the use case? Can it be deployed in a low-risk, low-cost manifestation at first, and then be scaled up to realize greater benefits?
- ▶ **Regulatory uncertainty:** What regulatory challenges can be expected, and how might they be addressed, when deploying the use case?
- ▶ **Applicability:** Does the use case address current needs and pain points specific to the nuclear industry?

### DT PROJECT PHASES

DT applications at a nuclear site require planned coordination among various technical disciplines. Generally, and on a high level, the process for building a DT application includes the following phases.

- ▶ **Discovery and design:** Collaborators agree on common goals for the DT application and work together on defining requirements of reach of the DT elements shown in Figure 1. This phase also involves establishing cost-benefit studies and a plan for maintaining the DT application going forward.
- ▶ **Infrastructure establishment and technology identification:** Collaborators evaluate the proposed use case(s), using the assessment questions identified above; work on selecting a DT platform suitable for the intended application, and identify supporting technologies (sensors, mixed reality, remote sensing, and so forth).
- ▶ **Digital twinning:** Develop DT documentations (procedures, training manuals, readme files, data storage protocols). Collaborators execute the plan and launch the integrated system, and identify any anomalies and work on resolving issues.
- ▶ **Life-cycle management:** In this phase, the DT application is fully functional. Data analytic tools are used to inform the life-cycle management of the asset(s). Perform regular maintenance to the DT, sensors calibration, and software updating.

As noted previously, assessment of enabling technologies readiness is an important phase of a successful DT application. The following are some opportunities for improvement in the enabling technologies.

### OPPORTUNITIES FOR IMPROVEMENT

As research on DTs and their use cases in the nuclear industry progresses, EPRI's research identified the following considerations for improvement to enable deployment of this technology in the nuclear industry.

- ▶ Sensors need to be robust and reliable to perform in the harsh environments of the various life-cycle stages, for example, rugged construction conditions, high radiation levels, and high temperatures.
- ▶ The success of ML/AI algorithms in reliably predicting and optimizing the performance of the asset/process represented by the DT is highly dependent on the quality of training data and the extent to which the training data capture the domain in which the ML/AI algorithms are expected to operate.
- ▶ Currently, computational power to realize near-real-time, high-fidelity simulations is expensive, which means that physics-based DTs requiring that capability must provide a substantial value to be able to justify such costs. Research is needed to develop efficient strategies for managing the integration of multiple physics-based analyses, maybe model-reduction methods, development of digital engineering guidance/procedures to direct engineers to develop models that meet the needs.
- ▶ DT, ML, and AI are emerging technologies; there may be limited precedent available on successful verification and validation, and new challenges may be encountered.
- ▶ Many DT use cases involve collection, processing, analysis, and storage of large volumes of data pertaining to the plant state. Accordingly, solutions need to be developed to manage the large volume of data expected as part of the DT application.

EPRI continues to research DT and the associated enabling technologies. The following is an update of ongoing DT projects at EPRI.

### A. DTs Applications for Advanced Reactors—Update

EPRI's research has identified and described over 25 use cases for advanced reactors (ARs) and classified them according to six life-cycle stages: design, construction, commissioning, operations, maintenance, and decommissioning. The use cases were defined based on a research approach including literature review, engagement with nuclear and non-nuclear DT subject matter experts, and discussions with stakeholders from the AR community.

A Technical Advisory Group (TAG) including AR vendor and utility stakeholders was formed to provide input to and feedback on the use cases and to guide the selection of two use cases with the greatest potential benefit for the AR community. The TAG members were individually surveyed to rank the different use cases with respect to the six assessment characteristics identified previously: technology readiness, cost, utility/value, scalability, regulatory uncertainty, and suitability for AR applications. A few of the highest-ranked use cases are summarized in Table 1.

TAG members have noted that the project design process and levels of development common in many other industries are lacking in the nuclear industry. These processes include BIM-enabled design and the related coordination and collaboration tools and processes. Many of the use cases that have been identified will be dependent on a high-fidelity design intent (BIM) model. These models will be further enhanced with additional data and detail during the construction phase. EPRI will continue to explore standards-of-care related to BIM-enabled design for nuclear facility delivery.

Now that the use cases have been generated, ranked, and prioritized, the research team will architect DT two top-ranked use cases. The architecting process will identify the elements and components needed for successful implementation, define high-level requirements for them, further assess technology

readiness, costs, value, scalability, and regulatory uncertainty, and document challenges and lessons learned.

For more information about this project, please contact Hasan Charkas, [hcharkas@epri.com](mailto:hcharkas@epri.com).

Table 1. DT use cases

Description	Target Benefits
<p><b>Real-Time Construction Sequence Optimization and Front-Running Simulations</b></p> <ul style="list-style-type: none"> <li>• A DT based on BIM that integrates 3D geometry, construction sequencing information, cost model, schedule, and so forth, to visualize and simulate detailed work sequencing.</li> <li>• During construction phase, use the DT to perform real-time optimization and front-running simulations informed by monitoring of schedule- and cost-critical parameters (for example, concrete curing; health, efficiency, and productivity of construction equipment; quantities of materials delivered and installed; current weather and forecast; environmental/health hazards; geolocation and biometrics of personnel; status of work products and inspections; supply chain data and predictions; billings from suppliers).</li> <li>• Real-time tracking of critical parameters enables identification and mitigation of suboptimal construction operations.</li> <li>• Front-running simulations provide real-time analysis of the likely consequences/outcomes of construction project events and deviations from the plan; provide construction management with high-fidelity information to support optimal responses to construction deviations.</li> </ul>	<ul style="list-style-type: none"> <li>• Improved efficiency of construction operations.</li> <li>• Optimized costs and schedule.</li> <li>• Early warning of personnel health hazards during construction for improved safety.</li> <li>• Informed ad-hoc decision-making based on knowledge of likely consequences of unplanned events that occur during construction and potential outcomes of mitigating actions.</li> </ul>
<p><b>3D Mapping and Augmented Reality Visualization of Ambient Radiation Levels</b></p> <ul style="list-style-type: none"> <li>• Integrate radiation monitoring sensor data with 3D building models to provide real-time, in situ mapping of ambient radiation levels throughout plant.</li> <li>• Equip plant personnel with mobile augmented reality equipment integrated with the ambient radiation maps and personnel location tracking to enable real-time visualization of radiation levels in the field, for example, safety glasses with projected images indicating radioactive “hot spots” to improve implementation of “as low as reasonably achievable” (ALARA) dose management principles.</li> <li>• Use pathfinding algorithms to guide personnel through optimal routes to their destination to minimize personnel dose exposure.</li> <li>• Compare real-time measurements from distributed sensors in plant and dosimeters worn by plant personnel with historical data to provide event-driven alarms and notifications of unexpected and new hot spots, which could be indicative of system faults, leaks, or malfunctions.</li> <li>• Couple personnel location tracking with contamination monitors to facilitate tracking, tracing, and cleanup of contamination sources.</li> </ul>	<ul style="list-style-type: none"> <li>• Enhanced personnel safety, reduced dosage.</li> <li>• Decreased personnel effort for performing radiation surveys manually.</li> </ul>

Table 1. DT use cases (continued)

Description	Target Benefits
<p><b>Predictive Maintenance</b></p> <ul style="list-style-type: none"> <li>Combine operating experience data (for example, EPRI’s Preventive Maintenance Basis Database, report 3002005428 [2]), real-time instrumentation data, mechanics-based modeling, and ML/AI algorithms to assess current health and predict remaining life.</li> <li>Used to inform and optimize maintenance activities, encouraging condition-based maintenance in favor of time-based maintenance.</li> </ul> <p><i>Specific Applications</i></p> <ul style="list-style-type: none"> <li>Condition assessment of electrical cables based on physics-based DT and operational history of the cables.</li> <li>Main Turbine Bearings: Monitor parameters such as number of operational cycles, bearing temperatures and loads, rpm, and so forth. Determine grease degradation using ML/AI framework trained on photographs taken during visual inspections, reducing, and eventually eliminating dependence on costly laboratory testing.</li> <li>Emergency Power Lead-Acid Batteries (and/or other electrical equipment): Integrate loading histories captured over the service life with performance and aging models. Monitor cell chemistry, battery temperatures, cell voltage, power cycles, power quality, response to loading and charging, and so forth.</li> </ul>	<ul style="list-style-type: none"> <li>Cost savings.</li> <li>Reduced maintenance.</li> <li>Increased reliability of equipment performance.</li> <li>Enhanced safety by minimizing avoidable/non-critical maintenance activities.</li> </ul>
<p><b>Prefabrication DT</b></p> <ul style="list-style-type: none"> <li>BIM-enabled prefabrication that leverages efficiency and quality found in the manufacturing industry (Industrialization).</li> <li>Incorporation of modularization and palletization consideration into design and a shift from traditional “stick-build” design methodology—Design for Manufacturing and Assembly (DFMA).</li> <li>Identify repetitive systems that can be designed and detailed once and built many times.</li> <li>Identify complex, multi-trade systems that are time and labor intensive to build in the field. These systems can be built off-site in a controlled environment with a higher tolerance and quality and then final-assembled in the field.</li> <li>Building high-detail models of systems necessary for prefabrication provides the foundation for DTs of the modular systems.</li> <li>Allows for standardized operational considerations such as maintenance access, consistent equipment placement, and modularized replacements.</li> </ul>	<ul style="list-style-type: none"> <li>Accelerated schedule.</li> <li>Increased quality.</li> <li>Less waste.</li> <li>Improved safety.</li> <li>Highly detailed systems models that support the downstream DT applications including predictive maintenance.</li> </ul>

### B. DT Tools Within EPRI Water Chemistry—Update

EPRI continues the update to the water chemistry tools for achieving a more realistic and accurate physical model of the plant secondary chemistry controls. This effort supports the steam cycle DT, including a plant-specific heat balance with the end goal of being able to adjust the plant-specific heat balance with actual plant data on a continuous basis, providing staff with a more realistic calculated output.

One of the biggest achievements to date is the improvement in the Plant Chemistry Simulator (PCS) [3] algorithm processing time that has significantly reduced the total time and usage for each processing cycle. This change in processing time increases efficiency in the application overhead and potentially allows for the identification of adverse trends earlier, using actual plant data, the PCS, and other adopted algorithms.

Other updates associated with the Smart Plants Works tools and supporting apps include (1) revisions to the code to incorporate the most recent EPRI water chemistry software code, including updates to the PCS and pressurized water reactor primary water pH(T) calculator; and (2) the scripting tool revision that allows for users to add custom scripts and code that is undergoing a major revision that should aid plant staff with incorporating other tools (for example, other data analytic tools).

These updates are intended to work more efficiently with actual plant operating data and other EPRI codes such as the data transfer tool connecting actual plant and chemistry data to

calculated data evaluating conditions on a continuous basis while continuously updating the heat balance file from the plant data historian(s).

The next phase of this project will be to identify collaboration opportunities for beta testing to verify the usefulness and practicality of this application.

For more information about this project, please contact David Perkins, [dperkins@epri.com](mailto:dperkins@epri.com).

### C. DT Tools Within Instrument and Control Program—New

The EPRI Nuclear Instrument and Control program has developed practical model-based engineering and advanced hazards analysis methods. Advancing these methods for integration into DT technology will provide “model-in-the-loop” capability for real-time plant operational analysis (Figure 2). This capability would detect complex off normal deviations caused by operator error, equipment failure, cyber security intrusion, or performance gaps.

The next step is to integrate ML into the real-time model loop to further dramatically reduce operator burden, especially in AR designs, and also allow maintenance and other support activities to be prioritized to correct the most potentially hazardous (economic or safety) condition.

For more information, please contact Matt Gibson at [mgibson@epri.com](mailto:mgibson@epri.com).

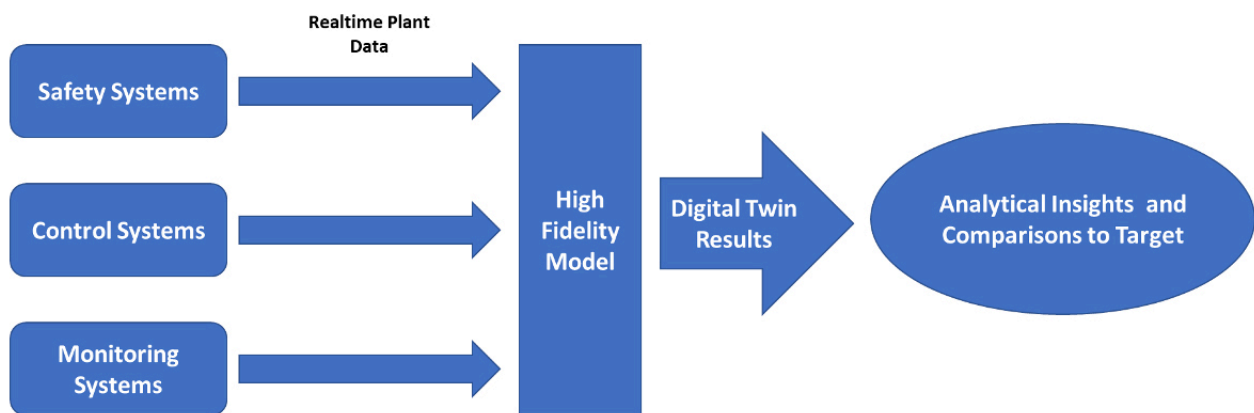


Figure 2. Real-time model-in-the-loop DT

## D. DT of a Real-Time Radiation Monitoring Network—New

As the use of remote radiation monitoring technology is increasing, the monitoring data collected are available in real time for display on the plant's internal information server. This EPRI project aims to evaluate and potentially use available geospatial technologies in conjunction with remote sensing data to simulate radiation fields and provide comprehensive models of the radiological conditions in between measurement points. It may be possible to then overlay the simulation on top of a 3D rendering of a plant to create a DT of the radiological conditions of the plant. In addition, the coupling of ML approaches to the geospatial algorithm to automatically refine the radiation field estimates will be evaluated. If successful, these methods will be tested and an initial cost-benefit analysis evaluation on the use will be documented.

Attempts will be made to make the modeling approach plant design-agnostic and adjustable to any plant site. The results of the simulation could be visualized by the workers during job preparations, job briefings, and the work environment using augmented reality techniques. These simulations would enable the development of efficient maintenance practices that can save time, reduce worker exposure, and reduce cost. The DT combined with ML could also facilitate automated ALARA planning.

For more information, please contact Richard McGrath at [rmcgrath@epri.com](mailto:rmcgrath@epri.com).

## SUMMARY

Recent industry workshops and government awards show increased interest in DT technology. The rate of research projects in academia and the industry is increasing, reflecting the growing realization of this technology. DT technology is not intended to solve all challenges in the nuclear industry but holds substantial promise for improving safety, reliability, learning, and configuration management. Like any other emerging technology, planning is an important element for

achieving successful application. There are key considerations for enabling value added DTs, which provide an opportunity for more collaboration among vendors, utilities, research entities, and regulators.

If you would like to get involved with EPRI on the DT topic or have some ideas and feedback for the DT team, please contact Hasan Charkas at [hcharkas@epri.com](mailto:hcharkas@epri.com).

## REFERENCES

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## EPRI RESOURCE

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