Key Takeaways

Water utilities are turning to “digital twins” to benefit their ongoing operations, improve planning, and enhance operator training.

As facility “flight simulators,” digital twins allow utilities to quickly investigate many solutions without putting equipment, public health, or the environment at risk.

Dynamic process simulations boost communication and collaboration, especially for teams with varied technical backgrounds.

Digital Twins: The Next Generation of Water Treatment Technology

Jason M. Curl, Tyler Nading, Kyle Hegger, Amer Barhoumi, and Monika Smoczynski
Water and wastewater utilities made a technological leap forward with the introduction of supervisory control and data acquisition (SCADA) systems. The next frontier of technological advancements is the use of facility “flight simulators,” or “digital twins,” that enable dynamic process simulations. Many water utilities are investigating or implementing digital twins to improve design of new facilities and to support operations staff training, reduce risk, and optimize operations.

If a single picture is worth a thousand words, then a digital twin of full-scale treatment and conveyance facilities is worth a billion (or more). Utilities are beginning to recognize that dynamic simulation models—which visually integrate design and operations components such as process flow diagrams, SCADA screens, and piping and instrumentation diagrams—can improve communication between project stakeholders, especially for teams with varied technical backgrounds and experience.

Society is just beginning to benefit from connected digital systems, often referred to as the Internet of Things (IoT). From refrigerators creating shopping lists to highways that vary tolls based on traffic loads, it is only a matter of time until connected devices, data analytics, and real-time machine learning are commonplace in every industry, including water. Here, we describe how utilities are leveraging advanced software tools to improve design and operations, and we highlight some of the lessons they learned.

How does a digital twin work within the context of a water treatment facility? Figure 1 graphically represents the flow of information among connected platforms, which forms the foundation of a digital twin. The digital twin becomes the central clearinghouse for data and visualization because it accurately represents the full-scale facility and its processes.

**Benefits of Digital Twins**

**Model Characteristics**

Digital twins can be leveraged to manage and operate all types of water-related infrastructure, including pump stations, pipe networks, storage tanks, and treatment facilities. Digital twins for water treatment and conveyance systems commonly have several key characteristics. They typically

- are hydraulically accurate for both pumped and gravity systems,
- have control logic that mimics system operation,
- operate on short (typically one-second) time steps,
- have an intuitive graphical user interface (GUI), and
- may include water quality and process performance.

While these dynamic models can be used for facilities ranging in size from 50 gpm to hundreds of millions of gallons per day, they provide the most value when there are complex interconnected systems or unique operational challenges that would benefit from improved understanding.

**Model Calibration**

Digital twins can be created for both greenfield and existing facilities. Calibration for newly constructed facilities is not required; however, calibration for existing infrastructure is an important component of the development of a valid digital twin model. For new facilities, model calibration can occur once the facility is operational and data can be collected.

Field data are measured with online instrumentation located throughout the system—e.g., flowmeters, pressure indicators, and level measurements. However, historical data often have gaps from when the measuring devices were not active, and there may be periods when the devices provided erroneous data that do not reflect actual performance.

The first step in calibrating any model is to identify events for comparison with the model results. Depending on the type of system that is modeled, a minimum flow, average flow, and maximum flow event may be needed to properly calibrate the model. For each event that is selected, flow, pressure, and level measurements are needed at as many points in the system as possible.

For an accurate digital twin, additional information that helps simulate a dynamic event includes pump speeds, valve positions, gate positions, and data from any other equipment used to convey flow in the system. If the digital twin is capable of process simulation, then additional water quality and process performance data may be needed.

During calibration, the hydraulic characteristics of the model are adjusted until the flows, tank levels, and pipe pressures predicted by the model trend within a
reasonable tolerance to what was observed during the event. Typical hydraulic characteristics that require adjustment include pump performance curves, orifice discharge coefficients, and pipe roughness. As additional events are tested and hydraulic characteristics are adjusted, previous test events can be resimulated to verify how the adjustments affect the model’s predictions over the range of flows.

The process of model calibration involves in-depth holistic evaluation of whole-plant data sets. While evaluating these large data sets, modelers can commonly identify characteristics or diagnose underperforming facilities that may not be completely understood by facility staff. Faulty or improperly scaled instrumentation, degraded pump performance, and hydraulic bottlenecks are examples of such findings. This is an indirect result of model calibration, which is useful for older facilities that have been retrofitted multiple times with varying levels of engineering and documentation.

**Facility Commissioning**

When starting up a new facility, one that has undergone retrofit construction, or an existing facility that is upgrading its control system, use of a digital twin greatly reduces risk in the early days of operation. The ability to test different control approaches in a virtual environment allows for rapid analysis of many alternatives without risking damage to equipment, overflows, or poor quality of treated water. In turn, this encourages creative thinking to identify new approaches that may deliver better solutions.

The ability to test new control approaches combined with increased understanding of the effects of these changes over the range of facility performance results in improved process control design and identification of control tuning parameters. For example, instead of controlling an intermediate pump station solely on the basis of feed wet-well level, a digital twin can inform an improved control approach; this could include a feed forward flow, from a summation of upstream flowmeters, plus a wet-well-level secondary trim. Additionally, pump transitions could be improved to minimize power demands or starts.

Ultimately, the use of digital twins promotes better overall system understanding, which also improves

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**A Digital Twin Forms a Central Repository for Information and Provides a Basis for Analysis for Treatment Facilities**

**Figure 1**
facility commissioning as various low-flow and high-flow cases can be tested in the computer environment well before construction is completed.

**Operator Training**
A digital twin can be further leveraged as a powerful operator training tool. With the GUI customized for easy navigation, the model can be used to isolate and explore specific layers, including an overall process flow diagram view, a detailed unit process view, an individual equipment view, and a controls view. Data can be plotted over time, and equipment performance can be animated for items such as pump speeds, valve positions, water levels, pressures, flows, and more. The digital twin can even incorporate the various alarms and notifications that operators would experience during full-scale facility operation.

The biggest benefit of using the digital twin as an operator training tool is the ability to “operate” the facility in conditions that are rarely observed in a safe environment. These conditions include equipment failures, extreme high or low flows, emergency shut-downs, and system restarts. Additionally, operators can test their own operational theories to understand the ramifications of their decisions without risking overflows or damaging equipment.

**Failure Analysis**
With a complete digital twin of a treatment facility, detailed analyses can be performed for extreme cases including failures. For example, a scenario for treating maximum design flows can be tested with major equipment offline; likewise, a scenario for treating minimum startup flows can be verified with equipment turndown. Team members can increase their comfort levels with operating under these extreme conditions in the safety of the simulated environment.

An added benefit of testing extremes is identification of potential shortfalls in the system's capabilities or realization of additional unplanned capacity. Without a computer simulation model, these conditions can only be observed under true duress, which does not allow for careful analysis and study.

**Analytics, Machine Learning, and Predicting Performance**
The addition of data analytics to a digital twin can further increase its value for facility operations. Data streams from online instrumentation to laboratory sample results can be centrally collected to identify outliers, which provides an automated method for data quality control. Once the outliers are identified and scrubbed, any data gaps can be automatically infilled. SCADA data can be backfilled once outliers are removed. Laboratory data can be infilled using seasonality models, autocorrelation, and cross-correlation to interpolate between points.

Once the data streams are analyzed and scrubbed, they can be uploaded into the digital twin and simulations can be run automatically. Parallel simulations can also be run with data variations to understand the sensitivity of the facility operations to the inputs. With results from the automatic simulations, facility performance for the coming hour, two hours, or even multiple days can be

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predicted. On the basis of these predictions, operations staff can be informed as to how to adjust their approaches to improve performance and/or reduce operational risk. Over time, the data analytics and performance predictions of the digital twin will improve, adding further value to the facility operations.

**Optimization of Facility Processes**

With a complete model, optimization can be conducted offline from the facility and could include linear and nonlinear optimization approaches—e.g., the evaluation of pump energy efficiency and relationships to operational requirements. Factors such as wet-well sizes, individual pump capacities, duty/standby requirements, actual pump curves, constant or variable speed, sequencing, ramp up, and ramp down can all be modeled and evaluated using these powerful models.

Another example is optimization of chemical dosing in a treatment facility. With available online data incoming to the simulation coupled with expected laboratory results (from seasonality assumptions and previous data), the digital twin can simulate expected finished water quality. When the simulations are parallelized and connected to optimization protocols, multiple simulations can be run—thereby increasing operators’ understanding of the proper chemical doses to improve water quality as well as to minimize production of solids and use of chemicals and power.

**Case Study**

The City of San Diego is in the first stages of implementing the Pure Water San Diego program, which will supply one-third of the city’s water by 2035. Phase one consists of multiple facilities, including new wastewater conveyance infrastructure (Morena Pump Station and pipeline), upgrades to the existing North City Water Reclamation Plant (WRP), the new North City Pure Water Facility (PWF), and new purified water conveyance facilities to Miramar Reservoir. A digital twin of the advanced water purification facility (Figure 2) will be used to improve commissioning and long-term operations as an operator training platform.

The North City PWF will accept treated tertiary effluent from the North City WRP. The PWF employs ozone, biologically active carbon (BAC) filtration,
microfiltration (MF), reverse osmosis (RO), and ultraviolet–advanced oxidation process treatment systems. This facility accepts more than 40 mgd of treated effluent and will produce up to 30 mgd for downstream potable water supply.

The city is employing a digital twin of the PWF to reduce potential future operational challenges. This simulation model runs on one second time steps and fully replicates the facility’s hydraulics, controls, and process performance. The dynamic nature of the model allows analysis beyond simply considering a minimum, average, and maximum flow case. The periodic nature of backwashes, flushes, drains, and recycles can be modeled.

The digital twin can also mimic the control schemes for the PWF. The BAC process feeds a wet well before pumping to MF. Additionally, there is a feed wet well before RO. These intermediate wet wells present risks for having unit process operations out of sync. The model can be used to verify control points as to when pumps should start and stop and how they should adjust speed in relation to other process operations and online instrumentation.

For example, BAC backwash operations will routinely affect the volume of water in the MF feed tank, which is meant to serve consistent flow to downstream MF and RO systems. Before construction, proactive and reactive control strategies can be tested in the digital twin under various scenarios to mitigate impacts of volume fluctuations.

Finally, the dynamic simulation model incorporate predictive process modeling. Water chemistry throughout the facility can be simulated so that chemical feed rates and use can be predicted as they relate to meeting water quality goals. Water treatment can be simulated using variable feedwater quality to leverage the dynamic nature of the model running over extended periods. Another key water quality parameter that can be monitored is process performance, such as RO membrane scale potential, finished water stability indexes, and log removal value of various microorganisms.

The city’s operators will also use this powerful computer simulation for training and to increase their understanding of the advanced water purification treatment processes onsite.

Conclusions

Facility digital twins that include dynamic simulations for hydraulics, controls, and water quality can provide an interactive, full-motion picture of a facility before it’s built. With a flight simulator model, operators can optimize their facilities offline under “normal” conditions and prepare for worst-case scenarios.

Testing what-if scenarios using these calibrated models is straightforward and helpful. Additionally, digital twins enable control systems to be tuned before starting operations, which can significantly reduce startup time and risk. Because the model can be run over the range of design conditions, control parameter tuning is more robust.

As the world becomes more connected through the IoT, water treatment technology and performance will become more reliant on data analytics and dynamic process simulation. Moving forward, more utilities will use digital twins to continuously improve operations with respect to solids production, chemicals, and energy—all while ensuring high-quality treated water is delivered to their customers. The use of digital twins is the next step in the future of water treatment.

About the Authors

Jason M. Curl is a principal water treatment technologist and digital twins global technology leader at Jacobs in Englewood, Colo. (www.jacobs.com); Jason.Curl@jacobs.com.

Tyler Nading is a drinking water and reuse technologist at Jacobs, Englewood, Colo.

Kyle Hegger is a digital twin project technologist at Jacobs, San Diego, Calif.

Amer Barhoumi is lead project manager at City of San Diego, San Diego, Calif.

Monika Smoczynski is assistant project manager at City of San Diego, San Diego, Calif.

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