J. CHELLANI, KBC, a Yokogawa Company, Abu Dhabi, United Arab Emirates; and G. WINTER and A. ALSHAIKH, Saudi Aramco, Dhahran, Saudi Arabia

Enhanced unit monitoring enabled by digital twin

Process engineers must continuously monitor the health and performance of process units. Unit monitoring ensures reliable operation of the unit, identifies disturbances early in the cycle and improves the understanding of the process. In addition, effective unit monitoring results in the identification of short- and long-term economic opportunities. These opportunities typically reside in yield optimization, cost reduction and maximization of unit capacity.

Unit engineers use key performance indicators (KPIs) to help define and measure progress toward the plant's business and strategic goals. They facilitate the management process by focusing employees on the critical measures of the plant's performance and keeping the achieved results in open view of the staff.

KPIs are quantifiable measurements—agreed to in advance—that reflect the critical success factors of a plant. They must reflect the organization's strategic goals and must be quantifiable. The key aspect of developing KPIs is in focusing them to ensure that only those KPIs that are truly reflective of plant performance are tracked and reported.

Pacesetters use a KPI tree that tracks performance of the assets and the overall site at different levels. Each level of the KPI tree has certain objectives associated with tracking and improving the performance of the overall site. The targets in this KPI tree usually follow a top-down approach, whereas the flow of information for reporting actual performance is through a bottom-up approach.

Monitoring the performance data of process units and key equipment is one of the main inputs for the KPI tree. The rest of the information at the different levels is estimated using unit-level KPIs. In the past, unit engineers have usually relied on raw data taken out of trends from the historian or on a laboratory information management system (LIMS). Experience in operating the unit, along with performing manual reconciliation, has been used by unit engineers to turn this into useful data; however, it is a time-consuming activity. In addition, the analysis is dependent on the individual's expertise, which is difficult to hand over to the next generation. Visibility of the analysis performed by individuals, and collaboration with peers, are also some of the challenges associated with unit monitoring.

Process digital twin. Increasing process plant complexity requires more sophisticated ways of approaching KPIs and targets. This is where real-time connected technology with deeper analytics—the process digital twin—comes to the forefront, as it accounts for the multidimensional factors and nonlinear trade-offs that make effective decision making a challenge.

These advanced analytics enable personnel to see inside assets and processes, and to perceive things that are not being directly measured. They are wired so that insights are instantly available without data and model wrangling by end users and are run in a consistent way that everyone can understand and agree on. In this manner, the process digital twin drives agility and convergence in understanding actions across the whole business. Key inputs used for a process digital twin are shown in FIG. 1.

Process digital twins are created using applications that are linked to data historians, allowing them to gather and process data directly from the historian without manual intervention. The process digital twin uses a standard, automated methodology to perform the following key tasks:

- Retrieve and screen process and lab data
- Reconcile unit material balances
- Calculate key, unmeasured process variables
- Calculate a set of KPI reporting information and targets
- Assess the health of the tools, including the linear programming (LP) model

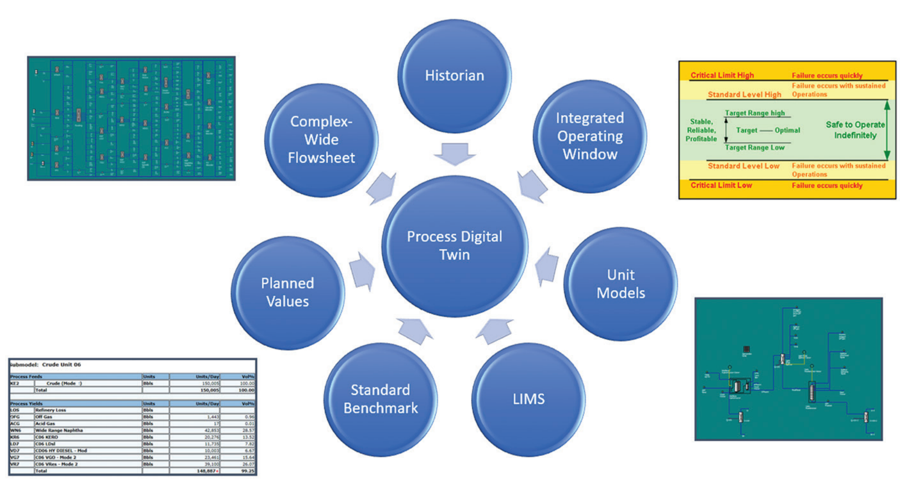

FIG. 1. Inputs used for a process digital twin.

- Generate user-configured digital reports (e.g., material balance—raw and reconciled—with data quality indicators that can trend and cross-plot all points and calculated KPIs over the selected time periods).

Unit monitoring ensures reliable operation of the unit, identifies disturbances early in the cycle and improves the understanding of the process. Effective unit monitoring results in the identification of short- and long-term economic opportunities.

As major decisions regarding operating and optimizing the unit are performed using the data, it is essential to identify issues with the data. Relying on the raw data without checking their stability and accuracy can lead to erroneous decisions. Due to this, the leading practice is for the process digital twin to calculate data quality parameters, which automatically validates the quality of data used to estimate KPIs.

KPIs calculated by the process digital twin monitor the entire performance of the unit, and, while some of these parameters are raw or reconciled values, others include complex calculations (e.g., the remaining life of catalyst). These KPIs are calculated using kinetics or equilibrium-based reactor models. Automating the calculations and consistent reporting saves a significant amount of time that unit engineers spend on this routine task.

One of the important uses of the process digital twin is model assurance, which ensures that the tools used for making business decisions are accurate and represent the actual performance of the unit. Process digital twins facilitate an efficient and standardized methodology for ensuring that plant data, LP predications and nonlinear model performance are kept synchronized. Having accurate data as inputs to the LP is an important element in making good commercial decisions regarding operational changes and product planning. Model performance indicators (MPIs), as calculated by the process digital twin, provide a comparison of the performance of tools vs. the actual unit operation. The MPIs can then be tracked in real time, improving the confidence level of the tools' users.

Visibility of information. Visibility of information is one of the major drivers for performance improvement in large organizations. Identifying lost potential and communicating it effectively are the first steps in reducing it. Simultaneously, variables associated with performance improvement need to be recognized.

Traditionally, refinery engineers have relied on spreadsheets and customized calculations configured by individuals. The information processed through this mechanism is accessible to selected individuals, and management lacks clarity of the information. Different versions of spreadsheets are often owned and used by isolated groups on an ad-hoc basis. Due to this critical performance, measures calculated by these groups may differ, leading to various reports with different sets of numbers being sent to management. This creates confusion throughout the organization.

To avoid confusion, utilization of the process digital twin as the analysis, calculation and reporting tool is recommended. As KPIs are calculated using first-principles models, custom-made calculations are minimized, which reduces dependencies on individuals. A centralized location is selected for the process digital twin, which is accessible to all stakeholders. The results reported can then be considered as the single version of truth. With all personnel using these results, it allows strong governance systems to avoid dependence on individuals. The flow of data through a process digital twin is shown in **FIG. 2.**

The most dynamic data—updated at frequent intervals—are the operating data from the process units. With continuous change in the feed quality and throughputs of the unit, the process digital twin needs to be updated at regular intervals. Other inputs can be updated on a monthly or quarterly basis, or as updated in other business systems (e.g., prices of feedstocks and products, and the integrated operating window).

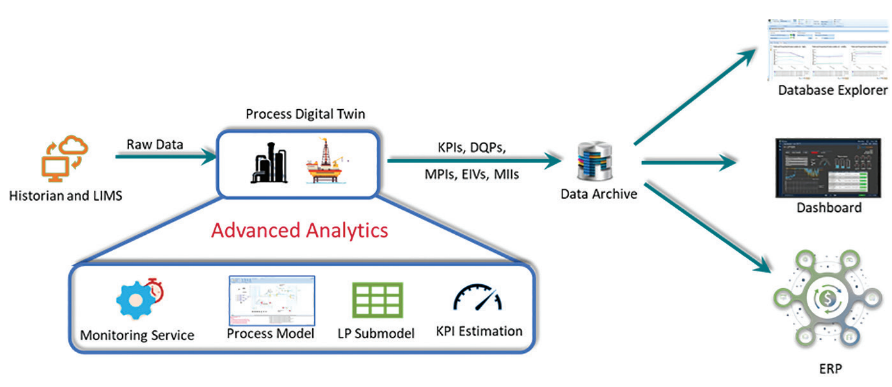

FIG. 2. Flow of data through a process digital twin.

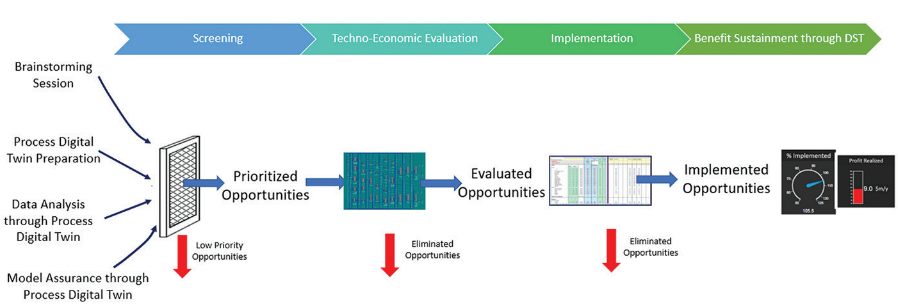

FIG. 3. Performance improvement and sustainment.

Performance improvement and sustainment. To build the process digital twin of a unit and for the overall site, it is necessary to understand the operating strategies before analyzing the data. Marginal mechanisms and constraints are identified during in-depth technical sessions and are validated using the operating data at a later stage. A brainstorming session, including the process expertise of all participants, is used to identify the gaps and opportunities.

KPIs calculated by the process digital twin often help identify additional areas for improvement. This is especially true for KPIs that are difficult to estimate and that are rarely calculated in normal operation (e.g., an approach toward equilibrium, fractionation efficiencies and flooding in distillation columns).

Process digital twins are validated on a continuous basis to provide an accurate representation of the asset over its full range of operations. Before deployment, additional insights regarding the operating trends can be found in the last few months of data. Variations of selected KPIs during a day, week or season also help identify areas that can improve performance of the process unit.

All the opportunities identified through the brainstorming session, the preparation of the process digital twin, data analysis and model assurance are screened. The opportunities are ranked based on the following criteria:

- Expected benefits from the opportunity
- Investment required
- Ease of implementation.

Qualitative analysis, rather than quantitative analysis, is performed to rank the opportunities. Based on the qualitative ranking, high-value opportunities are selected. These opportunities are pursued further for detailed techno-economic analysis, using the process digital twin as the main key evaluation tool. The opportunities are implemented, and benefits are proved through a controlled test run and demonstrated with the change in the KPIs (**FIG. 3**).

To sustain benefits from the implemented opportunities, selected margin improvement indicators (MIIs) are also configured in the process digital twin. MIIs indicate the gain or loss of margin associated with specific opportunities. The impact of MIIs is calculated using the process digital twin's ability to understand the complex-wide benefit calculation. Monitoring of MIIs ensures that the process engineers and operators continue to optimize and benefit from the opportunity. Deviations from the targets and associated losses are reported on a continuous basis and acted upon, thereby developing a culture of profitability in the organization.

Process monitoring: Hydrocracker unit pilot. Saudi Aramco and the co-author's company collaborated to develop a pilot of Saudi Aramco's first process digital twin for the Ras Tanura refinery's (RTR's) hydrocracker unit. The pilot project was a result of a Memorandum of Understanding between Saudi Aramco and the co-author's company. The application is designed as per the unit process specifications, with the objective to monitor unit performance and continuously recommend the operational optimum. This project was a collaboration

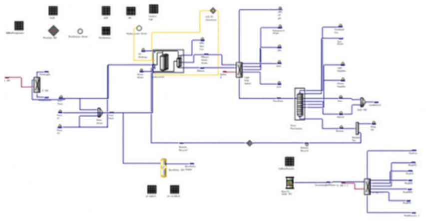

FIG. 4. Hydrocracker simulation model.

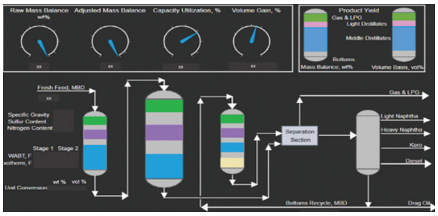

FIG. 5. Hydrocracker configuration dashboard.

FIG. 6. MIIs assign a relative dollar value to KPIs to guide unit operation.

between the RTR operations, RTR technical support, advanced solutions support and the co-author's company.

The process digital twin uses a kinetic hydrocracker reactor model to predict KPIs based on measured data. This model is also capable of predicting unmeasured KPIs, such as catalyst life and hydrogen solubility. The model also includes the effluent stripper, main fractionator, gas plant and a hydrocracker LP planning submodel to track the RTR planning model accuracy. **FIG. 4** shows the model of the hydrocracker unit.

Saudi Aramco chose not to use the co-author's company's default architecture[a] because the IT policies did not support data transfer to an outside cloud. Instead, the applications were hosted on Aramco servers, with a view to transferring them to the Aramco private cloud once the pilot was completed. A proprietary dashboard was chosen to display the process digital twin results. Multiple servers were used to enable the transfer of the data from the plant and from simulations to the dashboard and to create a process digital twin. Connectivity to plant data allows automation of the process digital twin application, including retrieving plant data, running the simulation engine, executing gap calculations and other analytics.

FIG. 5 shows an overview of the dashboard representing the hydrocracker configuration. The dashboard shows plant data validating KPIs and calculated to determine the plant data quality. It also determines when an investigation is required or when the dataset can be dropped for the period of bad data. The results of the process digital twin are displayed via a dashboard.

The pilot dashboard contains multiple displays, with each display configured to present a subset of KPIs, depending on the user. For example, the model quality parameters (such as mass balance) are displayed for the owner of the process digital twin to allow maintenance when required, while the reactor and overall unit KPIs are tracked by the process engineers. Process engineers can also access higher-level KPIs, such as MIIs. The dashboard is available via an HTML interface to authorized personnel. Other dashboards include:

- Unit performance indicators, including conversion, volume gain, yields, key product properties (e.g., density, distillation, nitrogen, sulfur and flash point) and plant data quality parameters
- Reactor performance indicators, including weighted average bed temperature, exotherm, catalyst life, treat gas ratio, CFR, stage hydrogen consumption, hydrogen solubility and leakage
- Model vs. simulation vs. LP submodel performance for yields, volume gain, hydrogen consumption, distillation 90% cut points, swing cuts and/or cut point shift
- MIIs that assign a relative dollar value to KPIs to guide the unit operation (**FIG. 6**).

The benefits from the process digital twin include:

- Improved unit production, yield and availability
- Enhanced unit energy performance
- Identified operational risks and hazards
- Improved productivity and operational effectiveness
- Consistent and systematic monitoring of multiple sites
- Knowledge sharing between Aramco departments.

The application can easily be expanded to include tray calculation and other equipment monitoring, as well as gap analysis on the results. In addition, data analytics can be included to calculate new LP shift vectors and other predictive analytics. The simulation model is always available to plant engineers for case studies, and the simulation data can be loaded for any past period. The results are available to authorized personnel via the web interface.

The process digital twin automates a significant portion of the process engineers' daily collection of data and KPI calculations, allowing personnel to refer to one consistent source of information. The process digital twin will allow engineers to spend more time identifying opportunities to improve refinery operations and margins, with less time validating and sorting data.

This application provides RTR engineers with a basic process digital twin of the hydrocracking unit to track the primary KPIs, including conversion, yields, catalyst life and others. The application also tracks the LP submodel performance and will enable the RTR manufacturing and planning economic unit (MPEU) to keep the hydrocracker shift vectors continuously aligned with the operation. HP

NOTE

[a] KBC Co-Pilot

JITENDRA CHELLANI is a Senior Consultant with KBC, a Yokogawa Company, in Abu Dhabi. He has more than 15 yr of experience in delivering consulting solutions for the refining and petrochemical industries. He is a subject matter expert for identifying and implementing opportunities for margin improvement. He earned an MS degree in chemical engineering from the Institute of Chemical Technology, Mumbai, India.

GABRIEL WINTER is an Engineering Specialist with Saudi Aramco. He has more than 20 yr of experience in the areas of process design, process simulation and optimization. In his current position at Aramco, he works with various departments and business lines to develop applications and solutions, using process simulation and optimization models. He earned a Bch degree in chemical engineering from the University of Texas at Austin.

AHMED ALSHAIKH is a Process Modeling and Optimization Engineer at Saudi Aramco. He has experience in planning, scheduling and supply chain optimization of Saudi Aramco's downstream business, including refining, terminal and distribution networks. In addition, Mr. Alshaikh has recently focused on the applications of the process digital twin and operational data analytics to the downstream oil and gas industry. He earned a Bch degree in chemical engineering from Heriot-Watt University in Scotland, and is pursuing his MS degree in business analytics and big data from IE University in Madrid.