Digitalization in refineries: A strategic roadmap for operational excellence—Part 1

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The refinery industry is one of the biggest industries worldwide. According to Statista, the global oil refinery capacity tipped 100 MMbpd in 2022.[1] This capacity reflects nearly a twofold increase since 1970.

Despite being big business, refineries are very capital intensive and may face challenges in maintaining profitability. The combination of costly capital assets, variable operating margins and strict environmental regulations makes it tough for these companies to adopt new and sometimes unproven technologies. Trial-and-error methods are expensive. Since most refineries lack the financial resources to invest in decarbonization and energy transition projects, they must find ways to leverage cost savings to transfer operational expenses toward capital expenditures. Furthermore, workforce concerns are a reality. As a result, leadership teams must strike a delicate balance between investing in new technologies while also fulfilling the refinery's fiduciary responsibilities. A critical aspect to consider includes evaluating the benefits and return on investment (ROI) that digitalization can deliver for both capacity and product diversity projects.

To remain profitable, big changes are needed. Digitalization is the pathway, and it is paving the way for refiners to compete, innovate and scale more effectively. With digitalization, operators can streamline product delivery and enhance customer satisfaction at lower costs. Refineries that seize this opportunity will realize improvements in agility, productivity and efficiency while achieving a distinct competitive advantage against their slower-moving counterparts.

Operational excellence. By harnessing the power of data-driven process solutions, refiners can improve efficiency. In the authors' experience, digitalization has been shown to increase productivity facility-wide by 1%–4%. Furthermore, automating processes typically improves employee productivity by 8%–15%. With cloud solutions, disruptions can be anticipated and responded to quickly, boosting ROI and return on capital employed (ROCE) by an average of 5%–10%. By extracting new value from data, refineries can experience growth and margin improvement, increasing operating income—which includes earnings before interest, taxes, depreciation and amortization (EBITDA)—by 10%–12%.

Challenges with digitalization. From probing customers to understanding their digitalization challenges, the authors' company helps customers face some common challenges that include:

- **Data security and privacy.** Digitalization efforts typically require transferring data to the cloud for easier access. However, cloud storage can expose a refiner's data and information to hackers and other malicious actors. In addition, refiners may lose control of their data in the cloud if they are locked into one vendor or cannot migrate their data.
- **Downtime.** Cloud computing systems rely on the internet, making service outages an unfortunate possibility.
- **Legacy systems.** Transitioning from dated systems can be cost-prohibitive. In addition, new digital solutions carry risks, and they may not integrate well with existing systems, infrastructure and processes. Also, employees may reject the new systems.
- **Change resistance.** Some employees may adopt new technology quickly, while others may be hesitant to embrace the change. This resistance can potentially derail digitization initiatives.
- **Data.** Digitalization efforts that are focused on data quality, along with effective data management, help refineries maximize their investments and create new sources of value. Companies must understand the availability, quality, scope and scale of their data, as well as how it is stored and accessed.

What is digitalization? Digitalization is not a new trend. Refineries have been applying digital concepts to improve operational excellence and safety since the 1960s. Today, a key difference is how this technology is being integrated into all aspects of energy operations from automation to data collection and analysis. Digital concepts enable refiners to improve operational excellence and safety at an unprecedented rate. Seven enabling technologies are leading the way to transform energy operations:

1. **Artificial intelligence (AI).** With AI, refineries can leverage large datasets to help provide analytics that produce actionable insights. These insights can be used in conjunction with cloud computing to drive decision-making that yields significant infrastructure cost savings while optimizing capabilities.For example, predictive maintenance involves gathering data from assets such as pumps, compressors and turbines, and then using that data to predict problems and/or failures. This data helps reduce downtime and maintenance costs while improving availability.
2. **The Internet of Things (IoT).** IoT sensors allow for the efficient monitoring of pipes, pumps and valves for leaks and damages in real time. This reduces the need for unnecessary manual checks, and workers are only dispatched when anomalies occur. IoT-enabled sensors collect and provide access to usage and maintenance data of remote assets operating in extreme conditions. These sensors also provide real-time data to control performance parameters, and this data can be used anywhere that requires monitoring.
3. **Automation.** Automating repetitive tasks allows employees to focus on value-added work. As an example, automated robots and drones can be used to perform dangerous and difficult tasks. Some of these tasks include inspecting pipelines and exploring hazardous environments quickly. Automated equipment can reduce time spent on repetitive tasks while helping workers install new parts, improve worker safety and increase overall productivity—e.g., automating the plant's control actions allows for safe and efficient operations.
4. **Blockchain.** Blockchain increases the transparency and security of digital transactions. Many refineries use blockchain for digital contracts to increase transparency between partners, especially for adhering to ethical practices. For example, blockchain can act as a digital notary. When integrated with the IoT, it also enables tracking the share of renewable energy injected into an electrolyzer.

5. **Augmented reality and virtual reality (AR/VR).** Real-time interaction with a computer-generated or real-world environment provides immersive experiences that enable employees to virtually explore the facility and simulate job-related scenarios. For example, AR/VR can be used to reduce training costs and improve competencies with operations and maintenance personnel.
6. **Digital twins: Modeling and visualization.** Digital twins are virtual models of physical assets and can replicate the facility's physical and operational characteristics. This software can significantly improve manufacturing processes by using data from virtualized infrastructure and equipment to improve efficiencies. Process digital twins represent the plant's process conditions through real-time simulation and consolidation of missing and/or inconsistent data. The engineering digital twin represents the plant's physical layout, containing the consistent design, engineering, maintenance and inspection data for each piece of equipment, pipe and instruments, among others. Process digital twins enable visibility inside assets, running "what if" and "what's best" scenarios in real time to identify strategies that maximize profits and ensure reliable operations.
7. **Cloud delivery.** Cloud computing serves as a decentralized shared resource. It allows a user to access software [software as a service (SaaS)], information and data from an external physical location. This resource provides avenues to develop plant-oriented solutions for more effective operations. Cloud computing can enhance information sharing and collaboration across data platforms and digital ecosystems. Refiners use cloud technologies to manage production, maintenance and efficiency needs. Collecting and analyzing data from equipment can determine when maintenance or further testing are needed. This analysis reduces downtime and increases output. They can also safely share real-time data between JVs and business partners.

Digital transformation process. Most refineries start their digital transformation process with digitizing, which means transforming analog data into a digital form, employing the most efficient means. By using software, data can be processed faster and more accurately, such as replacing paper-based work orders with digital work orders or converting manual readings to electronic readings. As shown in **FIG. 1**, digitizing is a well-planned process rather than an overnight job.

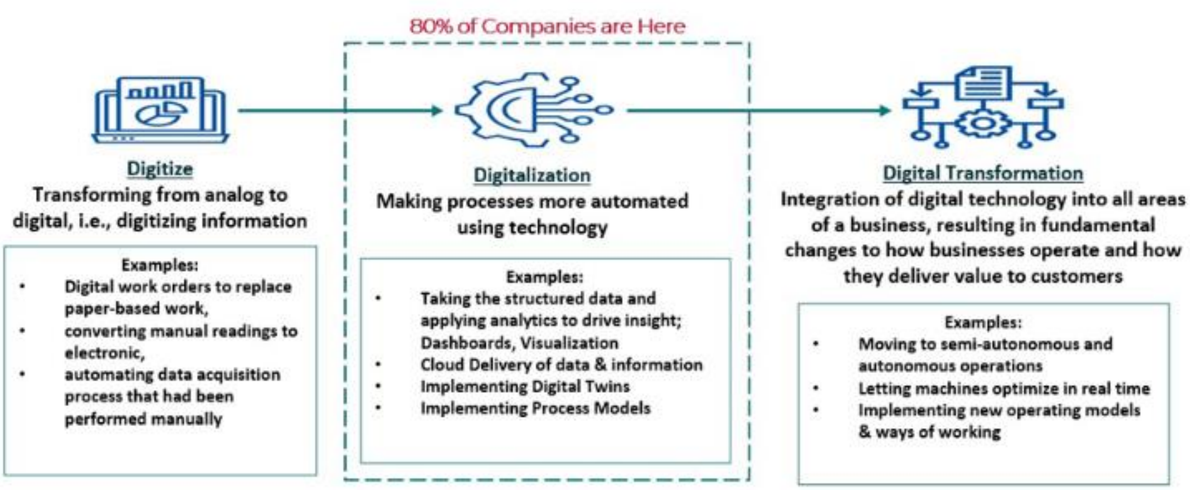

FIG. 1. The digitalization process.

After digitizing, the next step in the process is digitalization, which uses technology to automate processes. This step can include implementing a digital twin, or taking structured data and applying analytics to drive insights through dashboards or other visualization tools.

The last step is digital transformation, which will be covered in more detail in Part 2 of this article. Digital transformation is the integration of process, people, technology and data. It allows refineries to transition from labor-intensive manual systems to automated, efficient and reliable processes. Digital transformation results in a fundamental change to how refineries and plants operate and deliver value. Improved data management, predictive analytics and automation, process optimization, digitalization of operations, and transitions to semi-autonomous and autonomous operations can all add customer value. Digital transformation involves constantly evaluating opportunities and adapting to them as they arise.

DIGITALIZATION ROADMAP

Each refinery is at a different stage in its digital journey. To maximize their investment, refineries must focus on developing their business strategy, workplace culture and leadership team. To address this challenge, the authors' company has designed a five-stage digitalization roadmap (**FIG. 2**).

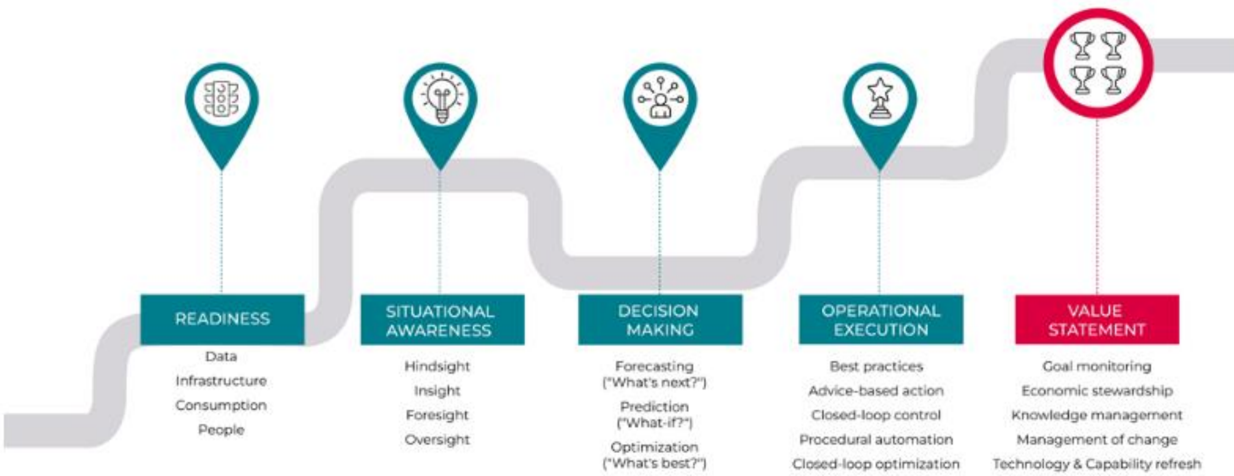

FIG. 2. The five-stage digitalization roadmap.

With this plan, leaders can identify gaps, channel resources, overcome barriers to reach digitalization goals and maximize performance while delivering competitive returns. Sustaining the benefits of digitalization requires proactive and ongoing effort to ensure that digital solutions continuously add value and align with the plant's changing needs.

Value sustainment ensures future success by uncovering gaps due to changing software and technology, as well as maturing goals. At this stage, every effort sets up a refinery for long-term success. Therefore, value sustainment is integrated into every step of the process.

From readiness to value sustainment, this five-step process steers refineries through the intricate landscape of digital transformation, culminating in long-term success. The following is a brief explanation and user case to illustrate each step.

Step 1: Readiness. Using data for decision-making purposes or feeding it into software applications requires a proven process to ensure data quality, which includes an infrastructure that facilitates consumption for the right people. The following business case explains how the authors' company worked with a client to improve its batch process efficiency.

- **Challenge:** Improvements to operational consistency and production efficiency were targeted as key digitalization goals by a specialty chemicals manufacturer. Despite its availability, the data was spread across multiple systems with limited capability for analysis. As a result, analyzing the data not only involved multiple manual steps and several different tools, but it also consumed much of the engineering team's limited time.
- **Solution:** A key element of the solution was extracting batch operations data from the dedicated batch monitoring system. With the batch data available, it was possible to structure the data, configure analyses and create visualizations to obtain a complete view of the data and analyses for easy consumption. While the solution was designed and evaluated as a proof of concept before scaling up, governance was established to guide implementation and solution sustainability best practices. This covered topics such as naming conventions, data quality, standard interface usage, security and access, and change management.
- **Results and impact:** With batch data available in an environment with a richer set of analysis tools, process engineers can now automate batch analyses and get results almost instantly. Furthermore, robust analyses can be completed by incorporating other data available in the analysis platform. The result was that process engineers gained in-depth knowledge of how the process works. Therefore, they can direct their focus on improvement opportunities rather than on tedious analyses.

Step 2: Situational awareness. Situational awareness provides a *"right now"* perspective into a company. Both hindsight and insight emerge from reports and dashboards. Hindsight involves analyzing the past for trends or patterns, while insight involves observing how things work now. Foresight uses analytics to project patterns and create forecast models, and leverages data to make improvements.

The following business case illustrates how the authors' company assisted a client to maximize production through an improved understanding of current operations through a digital twin, real-time analytics and visualization accessible to all stakeholders.

- **Challenge.** Meeting a refinery's hydrogen (H_2) demand for hydroprocessing requires proper operation of the steam methane reformer (SMR). This is important in renewable fuel processes with non-hydrocarbon feedstocks such as vegetable oils or animal fats. Historically, less attention has been given to SMR unit performance relative to other conversion and upgraded units, resulting in knowledge and experience gaps. A renewable fuels producer experienced difficulties running an SMR at full capacity. As a result, the economics of the renewable fuels process were affected. With no onsite team to diagnose operational problems, the producer used remote corporate specialists. By improving the visibility of current unit key performance indicators (KPIs) and gaps, the goals were to improve the understanding of the current production capacity and to help plan catalyst changes while reducing time spent troubleshooting performance.
- **Solution.** A process digital twin based on the authors' company's proprietary process simulation technology[a] was installed for the SMR to enable remote monitoring, visualization and enhanced analytics. The digital twin used first-principles models to represent the process reactions and perform analytics. On each test run day, the model automatically calculated an approach to equilibrium for each reactor section, based on observed process data, and on both online and laboratory analyses of the reactor inlet and effluent streams. The digital twin visualizations and analytics were configured to compare online and laboratory sample analyses for key streams in the unit, enabling quick verification of sampling quality, along with KPIs for process variables that impacted unit capacity. Additional analytics were configured to detect anomalies and suggest corrective actions. The visualizations were available in a company-wide system that provided simple remote access in real time.
- **Results and impact:** The onsite teams and remote corporate specialists used the data visualizations to collaborate on production planning and troubleshooting, as illustrated in **FIG. 3.** Following the turnaround, the online analyzer measuring the composition of process gas reported significantly different values. The analyzer was suspected as the culprit, but uncertainty was due to the catalyst replacement during the turnaround. However, the digital twin dashboard displayed a discrepancy between the online analyzer and lab sample analysis. The digital twin results confirmed that the discrepancy could only be explained by the online analyzer miscalculating methane levels (due to the implication of a thermodynamically impossible condition). The findings from the digital twin, along with the dashboard graphics, reinforced the suspicion that the site's online analyzer was faulty. This allowed the plant to swiftly replace the analyzer, minimize delays and enable the SMR to resume optimal performance.

FIG. 3. Data validation.

Step 3: Decision-making–Discovering the best answers. Digitalization shifts the focus from analyzing "right now" to "what if" scenarios to discover "what's best." Therefore, forecasting, predictive models, predictive analytics and optimization have become increasingly important. Ultimately, the key question is: Of all the possible options for improvement, which actions will return the most impact and economic benefit?

The following business case is situational awareness in action where the authors' company worked with a client to deliver automated analytics to improve maintenance and capital project decision-making processes.

- **Challenge:** Seasonal high temperatures, and the increased air-conditioning loads that accompany them, affect the operating temperature of electrical distribution facilities such as substations and feeders. In turn, these can impact the reliability of supply. A utility in the southern U.S. prioritized planned maintenance and capital upgrades ahead of anticipated extreme summer temperatures to minimize service outages. An annual system-wide peak load analysis was used to inform pre-peak season maintenance activities and investment planning activities. The underlying data that was needed to complete the peak load analysis was available. However, a study based on manual analysis took about 2 mos. While the study would be relevant to support decisions related to the next peak period, it would need to be repeated for the next year. As a result of the repetitive nature of the work and the interest in monitoring equipment performance during peak loads, an automated peak load analysis process was requested to be developed and delivered within the same 2-mos window. During peak periods, the process would provide real-time equipment monitoring, along with support for short- and long-term maintenance decisions.
- **Solution.** Using real-time operating data, equipment ratings and engineering operating limits, the solution assessed historical and current performance against critical equipment specifications and limits. Results were visualized in a business intelligence tool that generates notifications for overloads that exceed specified durations.
- **Results and impact.** Analysis of overloads is now a digital process rolled out to operations, maintenance and engineering teams. With access to current information and historical data (**FIG. 4**), teams can more quickly coordinate their efforts to identify potential reliability trouble spots during peak periods and to mitigate them. Maintenance, upgrades and operational changes that improve system reliability are more easily accomplished.

FIG. 4. System maintenance detail.

Step 4: Operational execution. Situational awareness and informed decision-making guarantee success in operations. However, achieving digital success requires implementing best practices. Once best practices and standardization are in place, the next step is automation by using advice-based actions. This expert guidance serves as the plant's "co-pilot," where a digital twin works alongside an experienced operator at a remote operations center. This collaboration provides an additional set of expert eyes monitoring the plant's performance. To optimize processes, closed-loop optimization is employed. As a result, system parameters are automatically adjusted to minimize costs or maximize objectives. The process repeats continuously and as rapidly as needed until the desired condition is achieved, without requiring human intervention. By following these steps, companies can drive digital success in their operations.

The following case study demonstrates how remote telemetry enabled a refiner to operationalize a new business model.

- **Challenge:** A startup green H_2 producer operating multiple small facilities with a limited onsite staff and decentralized corporate headquarters needed a scalable solution to remotely monitor its plants. Given the staffing challenges, it was key to implement a tool that would analyze equipment health and provide equipment degradation warnings to ensure timely maintenance and to optimize unit availability.
- **Solution:** A remote telemetry solution was configured to instantly send the process data via the mobile phone network to the authors' company's IoT hub, where it was historized, analyzed and visualized using proprietary software. Analytics were developed using input on equipment reliability metrics. The templated solution leveraged the proprietary software's asset framework and allowed for rapid duplication for future sites with minimal customization. Through a portal, the client could view dashboards and receive automated email notifications of significant events.
- **Results and impact:** The dashboard shown in **FIG. 5** provided an up-to-date window on plant operations. The gap-to-potential map in the bottom half of the screen highlighted KPIs that fell outside the acceptable range and were grouped into areas of suboptimal performance. These outliers were arranged in a visually impactful way. To prioritize remedial action, each issue was color-coded by type, with a size and color intensity proportional to its relative importance. Additional text assisted with the diagnosis and necessary action. In this example, the management team observed a potential issue with one of the compressors. By drilling down through the dashboards to examine the equipment in more detail, the team was able to make timely decisions and arrange for maintenance to inspect the compressor before this issue escalated.

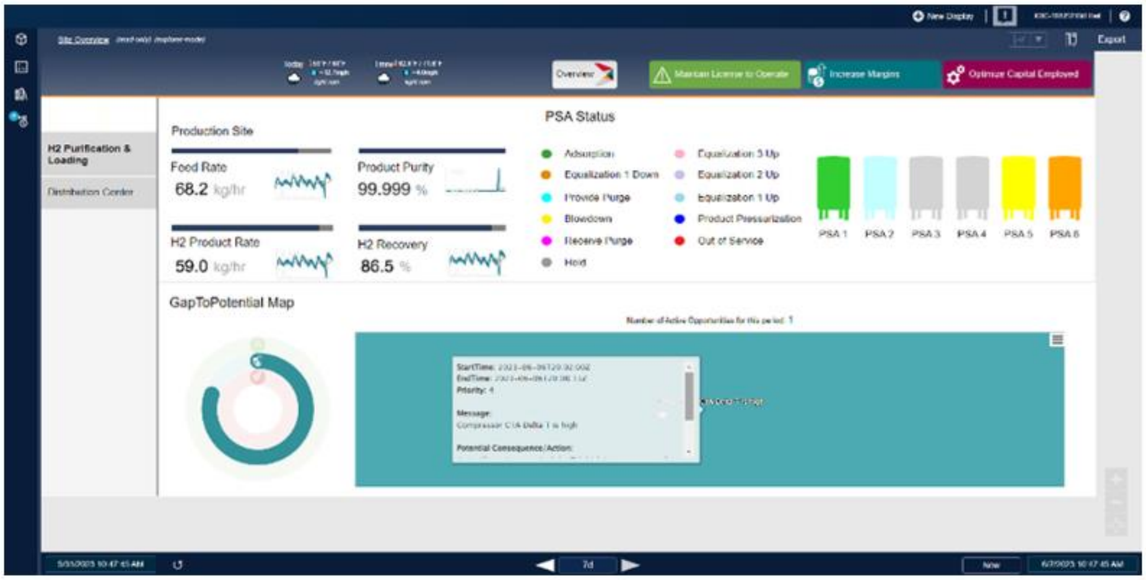

FIG. 5. Gas visualization.

Takeaways: Value sustainment. A universal, one-size-fits-all process for refineries is non-existent. Each facility has different operations and pursues different objectives. While every refinery does not need to become a digital disruptor, success hinges on tailoring digitalization efforts to match specific needs.

Leading refiners embrace this philosophy and harness digitalization as an asset. This includes identifying which digitalization strategies are most suitable and aligned with the refinery's goals. Some refiners use digitalization to find ways to improve efficiency, savings and customer experiences. Meanwhile, others use it to optimize their existing products and services by adding a digital component.

Regardless of how digitalization is used, measuring progress is key. Knowledge management plays a role in capturing tacit knowledge so it becomes explicit knowledge to foster resilience and shared understanding. Tacit knowledge includes skills, ideas and experiences that people have accumulated over time, but have not systematically codified in a way that makes this knowledge easy to express or transfer. Digitalization enables the complete sharing of this knowledge.

Change management is also vital for successful transformation projects. Establishing a governance framework ensures comprehensive control over technical aspects that drive program execution. This will capture critical success factors, encompassing not just the technical aspects of the program, but also the essential "soft" people aspects that are necessary for successful implementation of change and sustainable performance. Regular dialogue with stakeholders, along with transparent communication about program objectives and progress, are crucial to maintain motivation and achieve long-term success.

In an era of rapid technological change, a shift is needed in how technology and capabilities are approached. Proactive scanning and screening for opportunities that create significant value must replace reactive obsolescence concerns. While the risks and costs of upgrading technology are high, the potential returns are much greater, making these investments self-sustaining in the long run. Adapting to the digital age requires a strategic blend of customized approaches, effective change management and proactive technological upgrading. **HP**

NOTES

[a] KBC's Petro-SIM simulation software

LITERATURE CITED

1. Statista, "Refinery capacity for crude oil worldwide from 1970 to 2022," 2023, online: https://www.statista.com/statistics/264333/global-refinery-capacity-for-crude-oil/

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