Understanding the Digital Transformation

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Organizations in the chemical process industries are using digital tools and data-driven technologies to radically improve performance metrics. Determining the best areas to deploy these technologies is a challenge.

Oil refineries and other facilities in the chemical process industries (CPI) are up against some major challenges. They must balance safety, quality, profit, environmental compliance, and asset reliability. They contend with ever-changing regulations, fluctuating distribution patterns, global competition, and staff turnover. Any solution that is implemented to meet these challenges must inherently ensure flexibility to capture favorable market conditions and maintain a safe work environment while remaining in regulatory compliance. For an organization to thrive, it must apply the right knowledge across organizational and geographic boundaries while simultaneously working to reduce costs. These companies must adapt to survive. Fortunately, digital transformation is making a positive impact for those facilities faced with these demanding challenges.

Digital transformation refers to the leveraging of industrial internet of things (IIoT) technologies, software, services, and expertise to expand digital intelligence throughout a workforce, as well as augment workflows and processes to create new efficiencies and competencies that effect cultural and behavioral change within a company. When new technologies are used to fundamentally change operational procedures or establish new strategic initiatives across the entire organization — that's when a digital transformation takes place.

Digital transformation is sparked by rethinking and optimizing processes and by empowering personnel with the knowledge and tools to do their jobs more effectively.

Although benefits can be realized from new technologies, analytics, and subsequent behavior changes, it should be noted that digital transformation alone is not the solution to every challenge. Before understanding how to move forward with a digital transformation initiative, it is important to understand why an organization must move forward and how a new technology or more data can provide answers to operational challenges while netting a favorable return on investment (ROI).

This article discusses how to identify areas in your facility or organization that may be ripe for digital transformation. It also explains how to lead digitalization projects from the top down. The article concludes with a look at several relevant examples of successful digital transformation projects.

Big data as a driver for digital transformation

The term "big data" is used widely in articles, conference presentations, and press releases, yet it may not be fully understood. Facilities today have access to significantly more process and asset health data than they did a few decades ago. A single-train refinery built in the 1990s was designed to have 20,000 hard I/O points — *i.e.,* distributed control system (DCS) field input/output (I/O) connections. Today, that same single-train refinery would be designed to have 50,000 I/O points.

Having more data does not mean it is easier to operate the refinery — it just means there is an opportunity to have additional insight into operation and current asset health conditions.

The refinery of the future (and today) must embrace and implement shared intelligence, where sophisticated new technologies deliver the right information to the right person who can take corrective action when needed. Digital transformation brings the information to the expert instead of moving the expert to the data. The technology and processes themselves are also becoming smarter — automating the data analysis process and validating data quality. Organizations that have inexperienced personnel or high staff turnover can replace lost site-specific knowledge of retirees with technology that empowers the newer personnel to take appropriate action.

It is important to note that each site's strategy for digital transformation will be different, including refineries within the same fleet. Because no two operations are truly the same and every facility is at a different stage in its digital maturity, each facility will need a customized plan. Understanding where a facility currently is and where it needs to go is an important step in creating a digital transformation roadmap.

Crafting a plan for digital transformation

It can be difficult to plan for and implement a new digitalization project. Some challenges you may encounter include:

- the need for a clear vision of the digital transformation project and how it fits into the overall corporate strategy, and the means to communicate that vision to the rest of the organization
- the requirement to justify the investment required and work within budget constraints
- lack of available or appropriately skilled staffing
- lack of organizational or team leadership
- reluctance to upgrade or replace legacy information technology (IT) infrastructure as needed
- the need to protect the plant data and information from persistent cybersecurity threats.

The next section of this article provides best practices for planning and implementing a digital transformation strategy. This strategy will only be successful if the facility has a clear and focused business case, a scalable methodology, a flexible platform that can adapt as technology evolves, and a thoughtful plan for updating work practices to take advantage of useful and timely information.

Step 1. Perform a gap analysis

A gap analysis is a comparison of actual performance to desired performance. It determines whether certain requirements are being met — such as business, economic, or processing objectives — and, if not, the steps that should be taken to ensure those requirements are met. Although high-level metrics (*e.g.,* quartile rankings) can provide some interesting insights into how a facility compares to other facilities, the best way to perform a gap analysis is to brainstorm root causes of plant issues and formulate possible solutions.

The first step in executing such a gap analysis is to form a multidisciplinary team. Often, the staff working at a plant can become siloed into specific departments with little teamwork across different job roles. Having staff from different disciplines brainstorm about current site-specific challenges can provide valuable insight into the actual root cause(s) of the problem(s). It is commonly said that the more diverse the group, the greater the potential for innovative ideas. However, there needs to be respect among the team, and team members must listen to others' inputs to ensure effective collaboration.

You will find that some challenges are common across all CPI facilities. For example, at refineries, a common issue is processing discounted opportunity crude oils without increasing the risk of accelerated fouling and corrosion. Other challenges are site-specific, such as having new or existing staff that are not properly trained or suboptimal safety performance.

After the team homes in on a few key issues or gaps, they can identify areas where a new technology or digitalization strategy might help close the gap. A new vision or plan for digital transformation will begin to emerge.

Step 2. Lead from the top down

Determining how to benefit from digital technologies and processes can be complex. It requires industrial and technological expertise, as well as a deep understanding of the company's strategic goals and the condition of the facility. It also requires an understanding of the business workflow, operations and maintenance philosophies of the facility, and the existing roles within the organization and the need for collaboration among those roles.

After identifying gaps within the organization and deciding which digital strategies to deploy, the next step is communicating the vision to the organization. Although many people believe this should be the responsibility of the IT manager or the chief information officer (CIO), these important changes need to be led by the chief executive officer (CEO).

A recent study found that CEO leadership is essential for the significant changes a company must make to become digitally mature (Table 1) *(1)*. In fact, 41% of respondents at digitally maturing companies indicated that the CEO's office leads their organization's digital progress, compared with only 22% of companies in the early stage of their digital transformation.

The ability to digitally reimagine the business is determined by a clear strategy supported by leaders who drive change. Additionally, without a good vision and roadmap for implementing a digital transformation strategy, it will be difficult to define the ROI of the project as whole. Having buy-in and guidance from the company's top leadership ensures that the project will get off the ground and be roadmapped for success.

CPI companies typically have more improvement project opportunities than available funding and resources, which requires the company to prioritize and approve the projects with the best estimated financial return. Even if a digital transformation improvement project looks like a good idea on paper, it might not get approved without a champion in the C-suite.

Step 3. Identify missing data and required analytics

After identifying site-specific gaps and the path forward, the next step is to determine what measurements are missing and where new data will need to be generated, analyzed, or stored.

Online process and asset health data from sensors have been available for decades, but the way that we receive the data has undergone a transformation over the past decade. Wireless sensors, which are lower cost and quicker to install than their wired counterparts, are now favored; wireless products have been supported and fully compliant with the IEC-62591 (*Wireless*HART) standard since 2010. At many CPI plants, adding wireless sensors is an easy and cost-effective way to provide additional insight into asset health. And, it enables new and better ways to integrate work processes and improves the timeliness and accuracy of decisions.

A few options exist to improve the data analytics at your facility — from developing software in-house to purchasing software from solution providers. Advantages of in-house development include lower costs and analytics designed specifically for the needs of the plant; a disadvantage is that it takes time and effort to design and maintain the software. Although analytics software from a solution provider may require customization at an additional cost, it will be easier to scale up for many assets, and the software is maintained by the provider and includes preconfigured templates, updates, security, and patches.

Another consideration is data storage and distribution. For example, data from corrosion and heat exchanger monitoring should be sent to asset reliability engineers and technicians, since they are responsible for these specific assets. New data and information do not necessarily need to be sent to the DCS and the console operator. Because data may not go to the traditional DCS historian, IT needs to be involved in any new data analytics project.

The emergence of digitalization has noticeably increased the need for collaboration between IT and operational technology (OT) stakeholders. With the use of the cloud, data and information can be sent anywhere and viewed on multiple platforms, such as a computer, tablet, or smartphone (Figure 1). To maintain high levels of cybersecurity for data distributed outside the site's internal network, it is critical to involve and coordinate with IT.

Step 4. Implement the project and train staff

Once a digital transformation improvement project has been selected, it will need to be implemented. Many of these projects happen in stages and could be implemented over the course of a few years, which emphasizes the importance of communicating the vision and expected changes. Any changes in the facility will need to be properly documented, and management of change (MOC) procedures need to be followed for any technology, equipment, or procedural changes.

Because the team responsible for implementing the

Table 1. A study asked participants to identify the functional area that is primarily leading their organization's digital transformation.* As companies mature in their digital transformation, digital progress is more likely to be driven from the top down. Source: Adapted from *(1)*.

Early	Developing	Maturing
Information Technology: 23%	CEO's Office: 31%	CEO's Office: 41%
CEO's Office: 22%	Information Technology: 20%	Information Technology: 16%
Marketing: 10%	Marketing: 9%	Marketing: 7%
Operations: 7%	Operations: 7%	Product Development: 7%

* Percentages represent those respondents ranking the choice as first

▲ **Figure 1.** Before adding additional measurements and analytics capacity to your facility, consider where the data will be stored and who it should be distributed to. The emergence of digitalization means data and information can be sent anywhere and viewed on multiple platforms, including computers, tablets, and smartphones.

> In 1990, engineers required around 5,000–10,000 hours to design a refinery. Now, they can design the same prototype within 1,500–2,000 hours using advanced digital technologies.

improvement project often focuses only on the technology components, the people-side of the changes required for digital transformation often go unaddressed. However, training personnel and getting buy-in from engineers and operators are key factors for a successful implementation.

The people within the organization are critical in carrying out the digital transformation, but they might not be equipped to do so from a skill, culture, mindset, inclination, and/or talent perspective. Any improvements should be simple to understand, and key performance indicators (KPIs) should be provided to the personnel impacted by the improvements. If the process improvement will require the setup of a new alarm or alert, the alert should trigger only when an action is required; this will avoid nuisance alarms that distract people and deter them from using the new information.

Keep in mind that a digital transformation will empower each worker to do their job more effectively. This is accomplished with technologies and services that help personnel shift from routine activities like data collection to more value-added activities based on collaboration and business-critical decision-making. Properly trained operators are invaluable for a successful digital transformation, as they can confidently make decisions and act on information from analyzed data.

Step 5. Confirm and document results

After implementing a digital transformation project, a facility should evaluate and document its performance to better understand why the expected ROI was met, exceeded, or fell short. If the solution underperformed, the team should reevaluate it and determine whether small changes could capture the expected benefits. In addition, the team should regularly report the results of the improvement project to upper management to keep them aware of the progress made, as well as to get buy-in on new solutions.

Once success has been proven and the ROI has been justified, the initiative can be replicated at more sites. Applying proven solutions to specific problems can reap immediate benefits; this is an effective way for a lagging facility to start its digital transformation journey. Greater gains come from scaling a proven success across a facility or across the enterprise.

After a digital transformation project has been implemented, it must be sustained. Unfortunately, you cannot just implement the digital solution and forget about it. A specific individual or group must be responsible for maintaining the improvements. Those accountable also require ongoing management sponsorship and support. This is another reason regular reporting to upper management is essential.

Digital transformation examples

In 1990, engineers required around 5,000–10,000 hours to design a refinery. Now, they can design the same prototype within 1,500–2,000 hours using advanced digital technologies. And, they are multitasking — they are simultaneously working on many projects because of digitalization. The front-end engineering and design (FEED) time has come down significantly to approximately half of what it was without digitalization solutions *(2)*. This is just one example of the impact that digital transformation can have.

Over the past two decades, many mid-sized to large chemical processing plants and refineries are operating more efficiently with less resources while training workers to do more valued tasks. However, despite the shift in technology, standard operating procedures (SOPs) and overall behavior may still have a way to go — and field checks, data collection, reporting, and analysis may still be done manually. Without enough staff members, some tasks may unintentionally fall through the cracks, increasing the probability of a safety or environmental incident.

Behavioral changes and updated SOPs (even for maintenance tasks) must be employed to reflect the operational gains that new data and information from the digital transformation approach bring to the organization. The next sections provide a few examples of facilities that have implemented successful digital solutions.

Catalyst performance monitoring

Reactor and catalyst activity are very important to engineers in evaluating the performance and expected yield of a process. Catalyst activity for fixed-bed reactors changes over time due to catalyst poisons within the feedstock, erosion, and other factors such as high differential pressure that crushes the catalyst. Because the performance of fixed-bed reactors degrades over time, process engineers evaluate the catalyst performance daily based on process conditions (*e.g.,* flow, temperature, pressure, feedstock ratios) and feed and product properties (which are inferred or determined via laboratory analysis or online analyzers).

Many times, the data required for calculation and evaluation are in different databases that are not connected — for example, the laboratory information management system (LIMS) may not be connected to the DCS historian database that contains the process data. To make matters even more challenging, a mass balance across the reac-

tor must be performed to ensure the calculations and yield evaluation are based on catalyst performance and not data reconciliation errors.

At many refineries, catalyst evaluation can be a daily task that requires spreadsheets and manual data collection (even if the data is available in an electronic format). Further effort is required to validate the data quality prior to calculations and then evaluate the calculations for catalyst performance.

One U.S. refiner automated this process by connecting databases and implementing a data validation and analysis software system that included a mass balance and provided daily reports at the start of each day. The process engineers now are free to evaluate operations rather than spending precious time on manual data collection. In addition, when the process engineer is on vacation, the backfilling engineer has access to the catalyst performance reports without having to worry about how to collect all the necessary data.

Determining and mitigating utility bottlenecks

A refinery distributes hydrogen and steam to many users throughout the facility, making it difficult to measure the usage of each individual processing unit. When market conditions are favorable, refiners try to capitalize on the good margin opportunity; usually they increase throughput to maximize profits. However, this could push operations up against bottlenecks that limit production goals.

It is not uncommon to have a bottleneck caused by a hydrogen or steam limitation when a refinery is attempting to maximize throughput. However, without knowledge of the specific quantities that certain process units require, it is difficult to determine where the actual restrictions are and what units should be prioritized. For example, the hydrocracker is a workhorse unit in the refinery and has high value potential, so it may make sense for it to have the highest priority for hydrogen use. Unfortunately, it is not always simple to prioritize one unit over others. For example, other units require hydrogen to hydrotreat the feeds and protect the catalyst that converts raw feeds into higher-value products.

One refiner implemented additional measurements along with data reconciliation software to track the use of hydrogen in their facility. They also issued guidance to help their process engineers recognize when the system may be approaching a hydrogen-limited bottleneck.

Another refiner performed a similar implementation to improve their overall energy efficiency metrics. They tracked where steam was being used and whether it was being used efficiently, and they prioritized where steam was most needed in a steam-limited situation. They were surprised to see how much excessive steam was used in distillation columns. This information provided valuable insight that allowed them to reduce the steam rates to distillation columns that were over-refluxing and over-purifying product, which previously resulted in lower yields on certain products and hampered overall process flow through the columns.

Automated emissions reporting

As environmental and emissions regulations have increased, so has the pressure to maintain compliance and satisfy investors' calls to reduce emissions and impacts on the environment. Unfortunately, many refiners still collect this data manually to generate the necessary reporting. Like the engineers in the catalyst-monitoring example, engineers were manually collecting all the required environmental data. The manual data collection also included validating whether the data was good, which typically requires software. This data quality validation software can be created in-house or provided by a third party. Plants utilizing model predictive control (MPC) have been using data validation methods for decades in order to keep the advanced control running and functioning correctly.

One refiner expressed concern over the amount of time needed to collect and validate the data that is required to comply with regulations and avoid increased regulatory audits and fines. Although the objective was to automate the data collection and reporting, to ensure a financial return on investment, the refiner also included enhancements to reduce the emissions from fired heaters as part of the project. The facility replaced orifice plates and differential-pressure volumetric flowmeters on the fuel gas lines to each fired heater with mass flowmeters, which give more accurate readings when fuel gas properties change. Not only did the refiner successfully automate their data collection, validation, and reporting of emissions, they also benefited from more efficient fired heater operation, which reduced emissions and energy costs.

Asset monitoring and analysis

The traditional approach at CPI facilities has been to collect and store process data, and then use the data only to look back and evaluate process conditions after an incident. The digital transformation approach is to utilize the abundance of process and asset health data and predictive analytics software to automatically analyze data and turn it into actionable information. This new approach is forward-looking and alerts the operator before abnormal operation or imminent failure, giving facilities the ability to take appropriate timely action to avoid asset failure.

For example, process pumps were traditionally only monitored if they were part of a critical application. This required maintenance personnel to perform manual checks on those process pumps that were not monitored online. The frequency of those manual checks is typically once per month, or once per week for those pumps prone to prob-

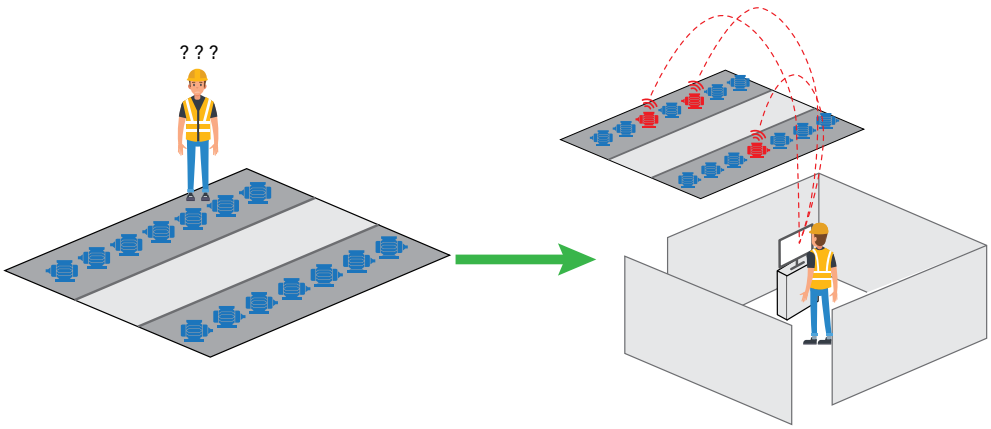

Figure 2. One refiner added wireless vibration transmitters to more than 150 process pumps. Instead of technicians looking for pump problems during manual rounds, the pumps that require attention are easily identified prior to failure and maintenance work is planned.

lems. Unfortunately, maintenance personnel cannot catch all problems and pumps still failed between manual checks.

One refiner added wireless vibration transmitters on more than 150 process pumps and distributed this information to the rotating equipment technicians and reliability engineers. Instead of personnel searching for pump problems during manual rounds, the pumps requiring attention are easily identified prior to failure and maintenance work can be planned (Figure 2).

Advanced analytics and machine learning

Newer tools like artificial intelligence (AI) and machine learning (ML) are beginning to play a role in creating operational efficiencies. In this area in particular, the CPI are transforming due to advances in algorithms and computer power. In 2018, several refiners that were early adopters of ML began piloting advanced analytics to determine patterns not easily recognized by engineers and console operators. In 2019, they presented results at the AIChE Spring Meeting that showed positive returns above and beyond expectations *(3)*.

In some successful projects, the engineers first deployed analytics to solve known problems with known solutions, which helped gain quick ROI and gave personnel confidence in these new technologies. Solving smaller problems first builds a foundation to continue solving more complex problems that may require a customized solution.

One refiner was piloting ML with the primary objective of reducing operating costs and overall energy consumption. The facility wanted to identify root causes of energy overconsumption immediately and accurately so they could quickly act on this information to modify operating parameters. The pilot was successful and saved several millions of dollars through reduced energy use. A few reasons behind the energy overconsumption included:

- the plant was occasionally running based on wrong setpoint targets, as they were not adjusted according to plant mode and states and crude oil changes
- gaps in knowledge and expertise between engineers analyzing performance deviations resulted in different decisions by personnel on different shifts
- the efforts required to diagnose the energy consumption issues were costly in time, money, and resources, so they were not performed regularly.

ML helped the facility to determine and analyze the root causes of overconsumption and then mitigate them. Other key benefits include increased visibility of the operations performance so that all personnel — from operators to senior management — could make faster and more informed decisions.

Analytics have advanced beyond just describing what happened or detecting what will happen. Now analytics software can provide guidance on what to do to avoid abnormal operation or imminent failure of an asset. Although it is important to understand what happened (descriptive analytics), in order to prevent asset failure or abnormal operation there is more benefit in predicting what will happen (predictive analytics). Advancing a step further, AI and ML systems can even advise staff on the required action

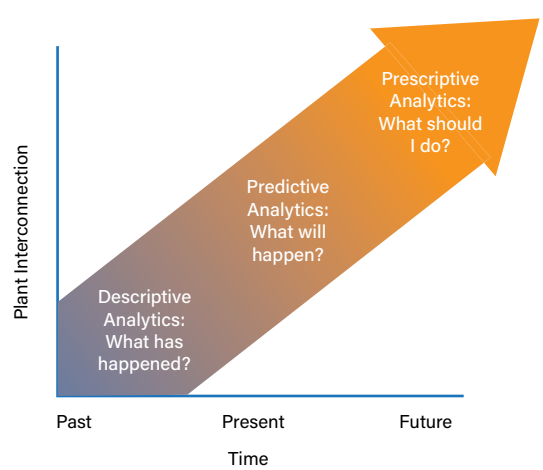

Figure 3. Machine learning enables facilities to move from descriptive analytics to prescriptive analytics.

(prescriptive analytics) to help avoid equipment malfunctions or unplanned shutdowns. In delivering prescriptive analytics, the processes, activities, and systems used in the plant become more interconnected (Figure 3). Prescriptive analytics look at data streams across these activities and pinpoint sophisticated signatures and patterns of data that are happening that may point to an event well in advance of that event actually occurring.

Final thoughts

Digital transformation strategies can be integrated with pervasive sensors that measure both process and asset health and generate valuable information that can warn facility personnel to take corrective actions when needed. However, in order for these developments to be effective, workers need to be trained and empowered to make effective decisions that will improve plant safety and operational effectiveness, enhance competitiveness, and ultimately improve profitability.

For a digital transformation to be successful, leadership needs to come from the top. Digital initiatives must be led by the C-suite and supported by all plant personnel. Successful implementation of a digital transformation initiative first requires you to clearly identify the path forward and the desired business outcomes. Only then can your facility deploy the solutions that will unlock insights and provide actionable information for tangible, meaningful results. Digital transformation in manufacturing is happening now. Are you ready? CEP

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