1

CHALLENGES FOR OPERATION EXCELLENCE

1.1 INTRODUCTION

Environmental, quality, and safety regulations are becoming ever stricter, and meeting the regulations is the license to operate manufacturing plants. In today's competitive environment, process plants are under more pressure than ever to deliver improved operating performance. Making the things even more challenging, the workforce is evolving, as an information technology (IT) savvy, but less experienced generation moves into roles once held by industry veterans, who have retired or are looking to retire. These trends are making the industrial norms to be rewritten, affecting profitability, reliability, and safety.

Thus, the industry is at a turning point. The answer lies in the digital transformation. To overcome the challenges, pace-setting companies have already applied digital transformation. The experience demonstrates that digitalization can turn a distracted organization—which is bogged down in reacting to day-to-day issues—into an agile, well-oiled machine that proactively anticipates issues and organizes to prioritize and solve them before they escalate. Thus, industrial companies need digital solutions to integrate different data sources with advanced analytics to make decisions in near real time to run their production processes more efficiently. Done right, it can empower personnel and makes the decision and implementation process more effective and can solve problems that could not be solved before. It can build a culture with digital information at the core. In short, digitalization seeks to

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achieve all that we sought from digitization in the past, albeit more effectively and efficiently. More importantly, digitalization aims to create new value beyond digitization by enhancing companies' business capabilities and achieving operation excellence across the entire operation value chains.

For most industrial plants, mere Industrial Internet of Things (IIoT) deployment is no longer a competitive advantage without understanding the implications of these insights. These advantages could be anything from improving safety to productivity to operational efficiency to workflow integration and automation. This is the part where true business outcome is delivered. To achieve the best digitalization outcome, it requires optimal integration of IT, operation technology (OT), engineering technology (ET), and data technology (DT). IT consists of computers, networking devices, and other devices to generate, process, store, secure, and exchange all forms of electronic data. OT mainly includes industrial sensors and control systems, while ET comprises process models simulation and optimization and best practices for operation. DT consists of data analytics and machine learning (ML) technology.

This integration of IT/OT/ET/DT creates significant value for companies and will lead to new business opportunities and growth. A properly designed digital twin is the best representation of this integration. The book will focus on the methodology of Connected Plant, which is designed to achieve the optimal integration of IT, OT, ET, and DT for operation excellence in the form of digital twins.

1.2 OPERATION ACTIVITIES IN A PROCESS PLANT

Process operation activities can be represented as a hierarchy (Figure 1.1). The foundation of the structure is composed of field devices (Level 1) such as sensors, transmitters, actuators, and valves that measure process variables such as flows,

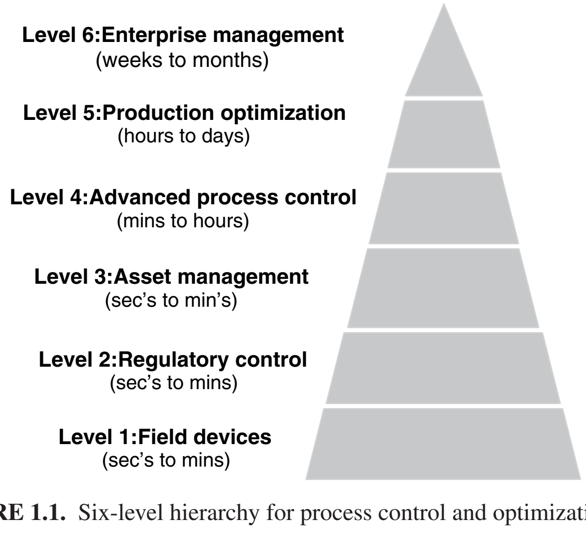

FIGURE 1.1. Six-level hierarchy for process control and optimization.

compositions, temperatures, and pressures, which are required for any industrial control system.

The next level (Level 2) consists of regulatory controllers, which maintain measured values within specified limits. Process control plays a key role in ensuring process safety and protecting personnel, equipment, and the environment (Level 3).

While regulatory controllers tackle each variable individually, the advanced process control such as multivariable and constraint controllers (Level 4) evaluates multiple variables simultaneously and enables an entire process unit close to a set of limiting constraints. To determine the optimum set points for a set of controllers, real-time optimization (Level 5) is employed, which also consider advanced control strategies beyond control modules, process supervision and coordination, shutdowns and start-ups, reliability and safety management, maintenance scheduling, etc.

At Level 6, enterprise management involves organizing and coordinating the operations of multiple plants. This level is the highest in the plant hierarchy and handles various functions including feed purchasing, production planning, scheduling, optimization procedures relevant to general production planning, coordination between different plants, feed movement and product delivery, etc.

The successful implementation of these six-level activities is a critical factor in making plant operation as profitable and reliable as possible. Levels 1, 2, and 3 are required for all process plants while the activities in Levels 4, 5, and 6 are designed for maximizing profit. Hence, the decision to implement the latter activities is driven by the company's financial priorities and economic considerations. The frequency of execution is much lower for higher-level activities, and the time scale of each activity increases up the hierarchy from less than a second to days and months. This is due to the need of production change cycle as well as the increase in computational requirements and analysis time from the lowest level to the highest. These activities are related and should be carefully coordinated. Levels 4 and 5, which focus on the control functions of advanced process control and real-time optimization for a process plant, are especially beneficial for a plant's operations.

In the above six levels, each layer depends on the previous layer in the hierarchy, and the control performance of an individual layer directly affects the stability of the process, the quality of the product, and the costs associated with making the product. However, running a single unit at its local optimum is not necessarily the best strategy for achieving overall profitability of the facility. This is where the production management layer steps in to manage the individual units' APCs in concert to accomplish plant-wide optimization. Furthermore, enterprise management coordinates multiple plant operations via optimizing feed selection and product generation and delivery to the market. That is where global optimum can be achieved for a company as a whole.

1.3 THE MAJOR CHALLENGES FACING THE INDUSTRIES

Changing market conditions put pressure on industrial companies. Increased competition and consolidation force businesses to speed up construction, engineering, and design cycles. Environmental, quality, and safety regulations are becoming ever stricter, and meeting the regulations is the license to operate manufacturing plants. Making the things even more challenging, the workforce is evolving, as an IT savvy, but less experienced generation moves into roles once held by industry veterans, who have retired or are looking to retire. These trends are making the industrial norms to be rewritten, affecting profitability, reliability, and safety.

1.3.1 Challenge 1: Supply Chain Management

In today's business environment, a lack of agility can hinder an organization's ability to be competitive. With high capital costs and ever-increasing energy expenditures, an organization can become locked into patterns where it is implementing shortsighted, cost-cutting measures that can adversely affect operational productivity—decreasing overall market responsiveness.

The bottom line is: maintaining a big picture view of key metrics—such as selecting and purchasing cheap raw materials and increasing manufacturing throughput, as well as transportations and logistics accuracy—helps minimize overall costs. This is done by optimizing the whole supply chain including business and production planning and operation scheduling of production processes, which plays key roles in the search for better profits.

Consider the oil refining sectors as an example. The supply chain of an integrated oil company stretches from the production and purchasing of crude oil to customers buying petrochemical products or fuel for heating or transport. Industrial supply chain consists of feed purchasing, delivery, feed mixing and scheduling, operation, and control (Figure 1.2). The management of such enterprise involves making decisions on what feed to buy and where and when? What processes to operate and how? What products to make? When each product is blended to make on-spec product to sell? What maintenance schedule for key equipment? How to integrate refining and petrochemical production? These decisions will be made repeatedly when demands and supplies change, production upsets occur, and transportation logistics change. A typical medium refinery may make products worth around \$10 million/day. The difference in profit margin between best and worst supply chain management could be at least around \$1/barrel, which is amount to \$100,000/day for a refinery of 100,000 barrel/day capacity. The value for the gap is very significant. Thus, refineries strive to optimize operation effectively via digital systems in order to close the gap and capture the opportunity.

Digital solutions for supply chain management can take advantage of cheap shale gas, renewable feedstocks and a wide variety of crudes that are available today while meeting product demand. In addition, many refiners have revamped their technology and expand petrochemical capacity so that they can achieve flexible operation between making transportation fuels and petrochemical products. These two trends have significantly increased opportunities for many refineries, helping them maximize and sustain margins in a competitive global environment. To take advantage of these options, agility in feedstock selection and accuracy in planning and scheduling as well as optimizing process operation and equipment maintenance to increase utilization is paramount.

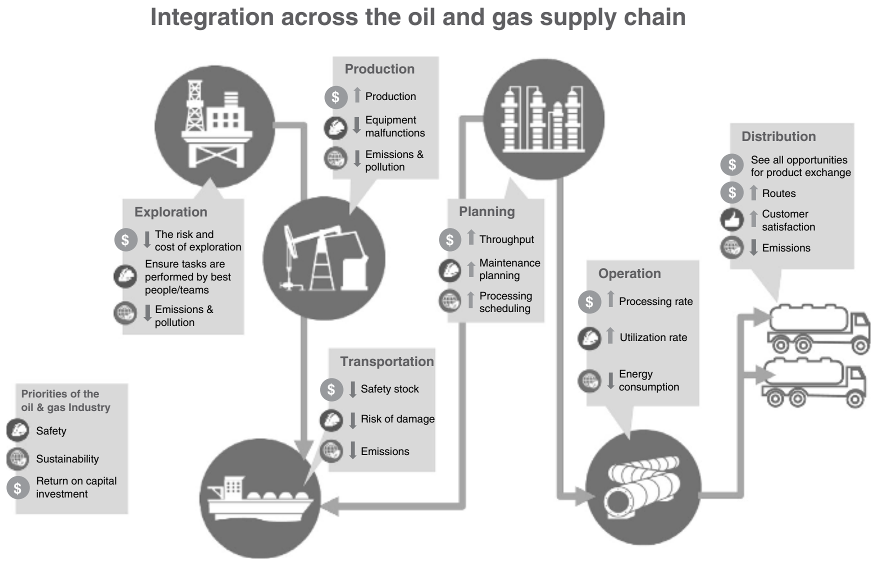

FIGURE 1.2. Manufacturing supply chain.

1.3.2 Challenge 2: Process Efficiency Improvement

The best process efficiency consists of three components: chemical efficiency, design efficiency, and operation efficiency. Chemical efficiency is the efficient use of raw materials. To get the best chemical efficiency, the key is to select the most cost-effective raw materials and select the best fit catalyst. A molecular modeling platform integrating reaction chemistry, kinetics modeling, and catalyst development is the key enabler to achieve high chemical efficiency. Design efficiency is about achieving the best technology selection and process configurations to obtain optimal system designs featuring low capital and operating costs. Process integration and intensification is the key enabler to achieve high design efficiency. Operation efficiency is how the teams operate the processes with high economic profit and minimum energy consumption via optimizing process conditions and better control. Integrated process optimization and control is the key enabler to achieve high operation efficiency.

1.3.2.1 Variability It is common that operation variability is a major cause of operation inefficiency. In general, there are two kinds of variability that can be observed in reality: inconsistent operation and consistent but nonoptimal operation. Figure 1.3 represents the operating data of a reboiler heat input as measured by condensate rate in the deheptanizer in a xylene isomerization unit. In Figure 1.3a, the heat input data points appear to be randomly scattered showing an example of inconsistent operation. This is usually caused by either poor control strategy or different operating philosophies used by operators for running the column. In contrast, Figure 1.3b shows a consistent operation, but one which is nonoptimal. In

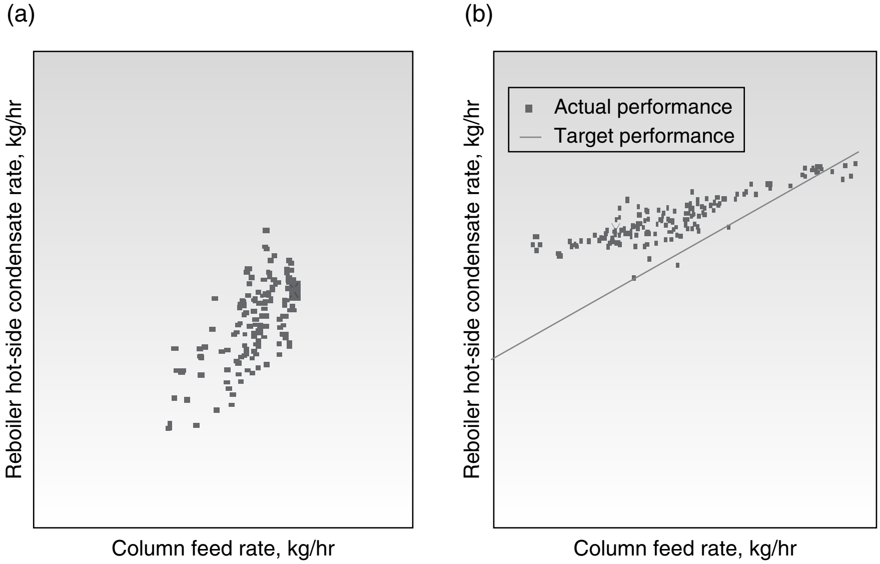

FIGURE 1.3. Two common operating patterns: (a) inconsistent operation and (b) consistent operation but nonoptimal. *Source*: From Zhu (2014). © 2014, American Institute of Chemical Engineers, Inc. Reprinted with permissions of American Institute of Chemical Engineers.

this case, a consistent operating strategy was adopted, but it was far away from the target for adjusting reboiling duty against column feed rate. The target operation represents the minimum reboiling duty required to achieve product specification.

1.3.2.2 Optimization If the operation practice or control strategy improves, the variability could be minimized to achieve more consistent operation (Figure 1.4b) than the base operation in Figure 1.4a, but the performance in Figure 1.4b still remains far away from the specification limit. The limit is usually set by a physical limit such as product purity specification, maximum temperature or pressure, maximum valve opening, maximum vapor loading in a separation column, maximum space velocity in a reactor, and so on.

Digital operation efficiency tools can help operators to improve further (Figure 1.4c), moving the average closer to the limit by adopting an integrated optimization and control strategy.

Digital solutions for process optimization and control can determine optimal reaction and separation operation as well as optimal control set points to maintain higher production efficiency under varying feed and product prices.

1.3.3 Challenge 3: Rigorous Model-Based Control

The fierce competition in operating companies has forced most companies to find ways to optimize plant operation. At the same time, increased computing power has provided opportunity for using comprehensive models to guide APC. In the past,

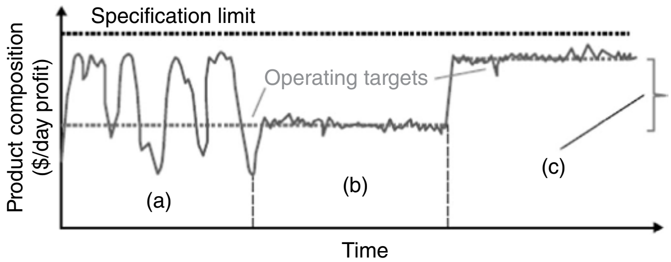

FIGURE 1.4. Operation performance: (a) current operation, (b) better control and reduced variability, and (c) increased profit by optimizing the set point. *Source*: From Zhu (2014). © 2014, American Institute of Chemical Engineers, Inc. Reprinted with permissions of American Institute of Chemical Engineers.

several modeling approaches are applied in the context of APC and regulatory control. These approaches range from empirical correlations to neural network (black box) and to shortcut models to rigorous models.

In recent years, the use of first principle based with autocalibrated models gains much attraction due to its ability in accurate representation of molecular information and nonlinear behavior toward more informed actions and implementation. This fact is even more compounded by the ever-increasing computing power at low cost and capability of data handling and nonlinear solvers for large problems. But it is a double-edged situation. In one hand, rigorous models can capture highly nonlinear behavior at fundamental level and thus can predict effects of changing feed types and process conditions more accurately. On the other hand, it is harder for process engineers to understand the prediction results than traditionally linear equation-based APC. In addition, it could become very difficult for troubleshooting of the root causes in the case of wrong prediction. Aggressive model turning can only shift error from one place to the other. Thus, the challenge is how to capture the benefit of rigorous models but avoid the difficulty of applying it for optimization and control purpose.

1.3.4 Challenge 4: Asset Management

In manufacturing, what is more crucial than the equipment itself? It is downtime, which damages business and costly for manufacturers. That is the reason why asset managers try their best to keep their equipment performing, despite constrained budgets and aging infrastructure. That is why equipment availability is one of the most important metrics for asset management.

Yet many organizations lack the insight and visibility they need to proactively refine their operations in a cost-effective way. In fact many organizations struggle to establish a benchmark from which to build an asset management strategy based on the basic information. Such information might include:

- Do we have a register of assets down to a significant level?
- Do we know the physical location of these assets?

- Do we know how many?
- Do we know the condition of the assets?
- Do we know, or are we able to report in the future, the life cycle costs?
- Have we assessed and determined a risk profile for these assets?

Digital solutions for asset performance management (APM) can reduce costs even as they reduce risk. The APM can analyze patterns, provide early warning signs for equipment failure, and respond with greater agility. The APM can also perform at higher levels of reliability, quality, and safety without needing more resources.

1.3.5 Challenge 5: Safety Management

Chemical process industry is a high-risk industry that can result in catastrophic casualties, loss of properties, and environment damage. Process safety should always come first in the chemical process industry. Effective process safety management is the guarantee for process safety in operation.

For many years, the approach to process safety management was more reactive. When some incident happened, the plant will review and revise its approach and then carry on until the next incident. Although the reactive safety management approach is useful when dealing with technological failures, or unusual events, its focus is on examination of actual failures only and compliance with the minimum safety requirements. This is a bit like driving a car by looking through the rear-view mirror. It is possible to stay in your lane, so long as there are no "curves." This is an expensive way to learn and manage safety. The chance of damaging the corporation's reputation is very real.

All major companies in the process industries have moved beyond this purely reactive mode toward more proactive approaches where major hazards are identified proactively and their risk is estimated and then managed. The team-based reviews are revalidated often in every five years. Over time, process industry companies develop a wide variety of safeguards to protect them against the potential incidents that the hazard identification teams have identified. But no safeguards are perfectly reliable—they tend to deteriorate over time.

This brings us to the newest developments in managing process safety risks— "digital twin for safety." With the real-time safety management (RSM) approach enabled by digital twin solutions, it is an even more proactive approach.

1.3.6 Challenge 6: Competency Management

Competencies are what people need to be successful in performing their jobs including the leaders and workforce. Competencies include all the related knowledge, skills, abilities, and attributes that define the competency of a person's job. This set of context-specific qualities is correlated with superior job performance.

However, the aging of the workforce worldwide has been called the "silver tsunami." With experienced personnel are set to retire, the workplace needs to prepare for a veritable tidal wave of turnover. The challenge is training young staffs to acquire the desired skill sets in timely manner. Digital solutions for competency management could provide effective training tools such as dynamic simulation, virtue reality (VR), augmented reality (AR), and so forth for training young professional to acquire and apply necessary skills and knowledge effectively.

1.3.7 Challenge 7: Workflows Integration and Automation

Technology on its own does not guarantee outcomes. The missing ingredient in order to achieve business outcomes is an organizational culture of excellence implying operating workflows and best practices—the more that these tasks are automated, the more repeatable the outcome. If a start-up or shutdown procedure can be automated, experience shows that the number of unsafe and costly incidents is reduced. If it pays to drive a plant up against its operating constraints, then automating that strategy so it can chase fleeting opportunities for improvement has been shown to generate huge returns.

Automation comes at a cost, however, and with some risk. The cost is the number of sensors required and the need for them to be reliable. The risk is how it behaves in the face of circumstances that was not designed to encounter. Our digitalization philosophy, therefore, is for our customers to invest heavily but wisely in automation and to mitigate the risks through good digital tool design practices and supervision.

Replicating existing business and technical processes in a digital environment does not assure delivery of superior results. Digitalization is more about the improvement of workflows and processes, organizational culture, and the application of knowledge and information in more effective manners rather than "just data." The focus should be on improving the existing best practices and work processes and thereafter finding the digital means to institutionalize automation of as much of these improved workflows as possible.

1.4 THE METHODOLOGY OF CONNECTED PLANT

To overcome the above challenges, the Connected Plant methodology was developed (Edwards, 2016). This methodology aims to connect **people**, **processes**, and **assets** within the organization much better than what has been doing with traditional digital solutions. The Connected Plant wants to achieve the following outcome for customers:

- Every day is your best day of production.
- Everyone in your organization is a leading expert.

- Can maximize the overall profit based on the market conditions and asset capability.
- Can maximize asset utilization via predicting and correcting abnormal situations.
- Can make the company be the best in the industry.

The Connected Plant is more than just data collection and software tools. It is about applying intelligent models to reveal insights. It is about integrating new digital solutions with existing data infrastructure. It is about better management of asset, workflows, and knowledge via digital solutions.

Industrial plants can benefit from being connected since they typically operate below their optimum output capacity due to process variations, unplanned downtime, and inconsistent workforce competency. Reaching and sustaining optimum levels of plant performance requires the transformation of real-time data into actionable insights. This will allow processes to operate at optimum levels for longer periods of time, identify and resolve asset issues before unplanned outages, and help every worker to operate as an industry leading expert. A Connected Plant is a single pane of glass software solution that collects real-time data and runs it through a digital plant model to predict and control deviations leading to optimized plant performance.

1.5 DIGITALIZATION ENABLING CONNECTED PLANT

The Connected Plant creates value through real-time data analytics, models, and optimization to reveal new insights for opportunities leading to turn-key solutions. It also applies advanced analytics and ML techniques to develop new heuristics and enable the solving of issues that we were previously unable to. It leverages the long-standing experience, paired with new digital technologies to resolve customers' issues better, faster consistently. It uses the cloud and edge capabilities to connect experts and project that knowledge back to operating companies. Use of the Connected Plant method can result in faster detection and resolution of operating problems as well as more effective best practice sharing and knowledge management.

Some might say, a digital system is about sensors, computers, software, and IIoT. The answer is yes and no. It is true that a digital system consists of these components; but that is not the point. It is what they do for value creation that matters. Digitalization solutions enable companies to manage day-to-day performance and achieve operation excellence. They can also help companies to response to market price swings quickly, operate the plant at a true optimum in order to squeeze the gap between potential and realized margin, and outmaneuver the competition. Let us dig deeper a little more.

1.5.1 Four Key Components of a Digitalization System

A digital system is an information gathering and processing system that converts data to insight via digital twin models, which helps plant staffs to make more intelligent decisions. There are four major components in a digital system, namely, IT technology, OT, ET, and data technology (DT). IT consists of computers, networking devices, and other devices to generate, process, store, secure, and exchange all forms of electronic data. OT mainly includes industrial sensors and control systems, while ET various process models simulation and optimization and best practices for operation. DT consists of data analytics and ML technology.

1.5.2 What Is New That Digitalization Can Offer?

Industrial companies have been using traditional IT, OT, and ET in combination for many years. DT is the new component that will be added. So, what is new that the digitalization can offer?

Digitalization is mainly originated from several major breakthroughs in IT and data science in recent years. First is that the computing power has increased exponentially together with cloud technology, both of which make processing and storing of big data possible.

Second, with the advent of Internet of Things (IoT), it connects data from different sources (on-premise, edge, and cloud) and makes the internal and external connectivity possible via smart sensing/wireless sensing technology. The smart sensing and wireless sensing technology can measure equipment performance from remote locations so that the measurements in various locations can be connected to the data center in a cost-effective manner.

Third, digital twin creates a virtual plant based on rigorous and analytics models and data available in plant historian to mimic the real plant. Digital twin can analyze "what-if" scenarios, predicting "what's wrong" events and determining "what's best" conditions in an automated manner. Due to cloud, digital twin can be provided and maintained by third parties, and the predicted results are displayed in cloud for visualization. External specialists can provide technical supported if needed.

Fourth, the advancement in data science technology (DT) and artificial intelligence (AI) introduces new capability of prediction based on statistical and ML algorithms, which are mainly applied for predicting equipment failure mode in manufacturing plants.

Therefore, digitalization, based on new IT, smart sensing, rigorous models, and data science technologies, can connect people, processes, assets, and products in both the physical and digital worlds and enhance operation excellence to a leapfrog new level. It is natural for companies to consider to take advantage of the digitalization for the goodness of the entire organization via improving connectivity among people, assets, process, workflows, and tools under stronger competition in the market and a growing scarcity of skilled staff.

1.5.3 Collective Excellence: The Objectives of Digitalization

Digitalization should be developed for value creation via IIoT, cloud and edge, and models for deriving insights and integration for automated workflows to address end-to-end enterprise touchpoints (Figure 1.5). The overall goal that we wish to accomplish via digitalization is operational excellence, which is defined as "the execution of the business strategy more consistently and reliably than the

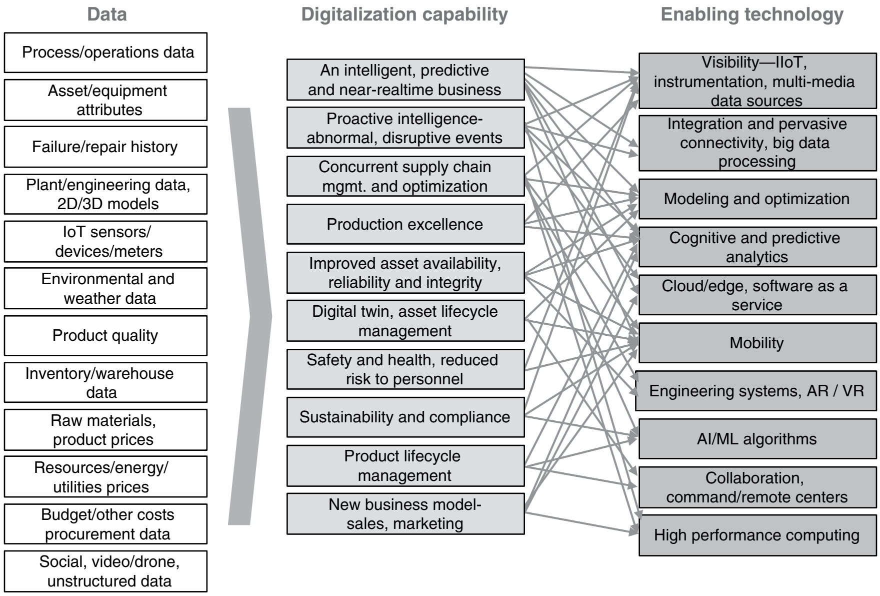

FIGURE 1.5. Overview of industrial digital system.

competition. Operational Excellence is evidenced by results." Given two companies with the same strategy, the operationally excellent company will have lower operational risk, lower operating costs, and increased revenues relative to its competitors, creating value for customers and shareholders (Francisco, 2017).

Specifically, operation excellence includes the following elements:

- Identify and sustain the value from continuous changes.
- Discover new revenue from unexploited feed selection and product gains.
- Maximize process throughout and equipment utilization.
- Predict failure mode with much early warning signs.
- Preventive maintenance.

While many companies have looked at various ways for implementing digitalization, very few have taken the holistic view of applying digital transformation to close gaps in current business and technical processes with a clear perspective of prioritized opportunities and adopt the outcome-based approach. Digitalization transformation should be centered around value creation instead of doing it for the sake of IT technology under peers' pressure.

Companies can see the potential of the digitalization in helping them to improve connectivity among people, assets, tools, and workflows to make the whole company/organization more *collectively intelligent*, agile, and efficient via integrating business, technical, and operation activities.

1.5.4 What Is Collective Intelligence?

Broadly speaking, intelligence includes the capability of problem solving using combination of logic, understanding, creativity, experience, wisdom, and learning as well as emotional knowledge and self-awareness. In the context of this book focusing on industrial topics, we adopt the definition by Tegmark (2017):

$$\text{Intelligence} = \text{ability to accomplish complex goals} \tag{1.1}$$

Collective intelligence is the combination of different expertise, methods, and tools toward the same goal that is operational excellence in the context of outcome-based digitalization. Thus, collective intelligence can be expressed as

$$\text{Collective intelligence} = \text{goal} + \text{agency} + \text{smart} = \text{value fully realized} \tag{1.2}$$

The operation excellence companies are collective intelligent featuring three key qualities: a sense of purpose, agency, and smartness.

Thinking of purpose here as a lofty goal of operational excellence that provides a clear direction for all personnel within the company and everyone plays a part in it. But it takes extraordinary initiative involving effort, knowledge, experience, and wisdom to accomplish the lofty goal. This initiative is called agency. People with strong agency will take the initiative, "let us do this!" and then follow through with actions for implementation.

Regarding smart, it is similar to intelligence as defined in Equation (1.1), which can be complemented by the Oxford Dictionary definition "the ability to acquire and apply knowledge and skills to solve problems." Thus, we think "company smarts" as: the ability for the company to face challenging tasks with collective intelligence to learn and figure out and take informed strategic decision to solve the problems.

So, the million-dollar question is: how can the digitalization help improving company's collective intelligence? The answer is very positive. The pace-setting companies are already using digitalization to holistically integrate business and technical data and activities via integrating data and workflows to determine:

- Convergence of planning, scheduling, and operation optimization:
    - Planning optimization (what): what feedstocks to buy and what products to make, and in what quantity?
    - Scheduling optimization (when and where): when to receive what feeds in which tanks, when to blend them (if needed), and when to blend and deliver finished products, in what quantity?
    - Operation optimization (how): how to run individual processes via setting operating targets to guide APC and regulatory control systems?

- Asset management (what-if and what's next): what failure mode could occur to which equipment and when?
- People and skill management (who and what): who to be assigned to what tasks based on the skill requirements?

Furthermore, these companies use digital twin models for operation excellence. The digital twin located in cloud or edge gathers data from different sources including sensors and soft sensors, DCS, historians, and labs as well as feedstock and energy pricing data. The digital twin can not only determine optimal operating conditions but also assess what-if scenarios and predict future failure events.

Therefore, digitalization can enhance the capability of accomplishing complex goals. In addition, use of data analytics and machines learning enhances the ability of learning from existing data and deriving new insights. Now we can conclude that digitalization can improve company's collective intelligence for problem solving proactively and creating value for the organization via converting the data and models to insights that helps human to make more informed decisions.

The best outcome for digitalization is achieved by the proper integration of IT (big data and connectivity centric), OT (procedure and control centric), and ET (model and optimization centric) together with DT (predictive analytics centric). The outcome is to have effective response to market environment and achieve company's objectives via making recommendations for business changes, deriving new insights for operation, predicting new events and opportunities, detecting early warning signs of failure, optimizing workflows, and enabling more intelligent actions for better profit, efficiency, reliability, and safety (Figure 1.6).

1.5.5 What Is the Human's Role in Digitalization?

No matter how intelligent the digital solutions are, human must act upon. Otherwise, nothing would happen. It takes deep know-how, experience and courage to take intelligent

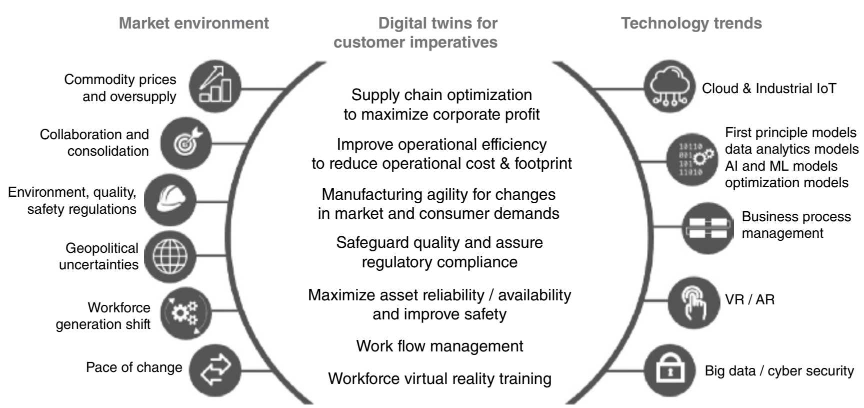

FIGURE 1.6. Integration of multiple digital twins: outcome-based digitalization.

actions with confidence to make successful implementation to capture value. The simple truth is that digital solutions are not taking over the world nor are they obviating the need for human in the workplace. They are simply amplifying people's skills and collaborating with plant personnel to achieve the true potentials of digitalization.

Digitalization is not just a bunch of technologies and people may think the job is done when all the necessary IT technologies are installed. No! Digitalization is just an enabler for achieving operation excellence more effectively. Digitalization is only the starting of the journey for achieving operation excellence. A continuous system with effective work processes in place for operation excellence must be developed with strong leaders driving it. It is a never-ending journey.

With the digitalization, companies need special skilled people in the IIoT environment. Simple and monotonous processes are being automated via digitalization, but other processes become more complex and intertwined.

There are three major components of human interactions with the digitalization process, which could miss in the middle between human actions and digital solutions (Figure 1.7). We call this the "missing middle"—"missing" because virtually no technology vendors talk about it; only some pace-setting companies are taking dedicated effort to fill this crucial gap. These three missing-in-the-middle components are briefly defined below:

(a) Trainer: Validate the data quality and digital twin models when feed type and catalyst type change significantly; digital twin models need to be calibrated manually prior to deploying online. For machine leaning models, it requires extensive training prior to applications. The model turning and training are conducted by subject matter experts from technology vendor. Once the models are running online in nominal situations, data validation and model turning are conducted automatically within digital twin. If digital twin is located in cloud and supported by technology vendors, the role of trainer is performed by vendors.

(b) Explainer: Interpret the model results with the relationships between parameters of interest and their implications and value to the company. The responsibility of the explainer's job is to bridge the gap between technical

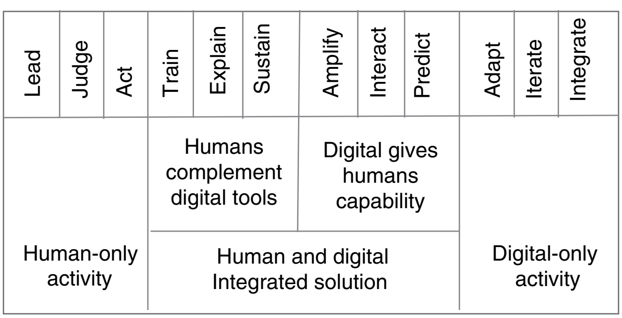

FIGURE 1.7. Human's roles in digitalization.

personnel and business leaders. As companies rely on the digital twin to determine actions, some of the actions that push operating limits may affect profit, reliability, and safety. Explainers need to able to explain and justify those decisions. They must understand the inner working mechanism of complex models as well as practical operating limits and able to explain the reasoning of digital twin and rationale of the recommendations. In addition, they may also assist the implementation team to provide support for conducting what-if analysis using digital twin during the implementation process and estimate the value capture during and after the implementation.

(c) Sustainer: Subject matter experts may act (like a "babysitter") as sustainers of digital twin. They must work continually to ensure that digital twin systems are functioning properly to avoid any misleading predictions, which could lead to operation trips or disaster in the worst case. They oversee the digital twin performance, remove bad data, impose new limits (reliability, economic, legal or ethical), maintain models and make exceptions where necessary.

1.6 WHAT IS THE DIGITALIZATION JOURNEY?

To decide what digital applications and capabilities are required, one must identify the problems or pain points that negatively impact operational excellence. Once these problems are known and understood, the next task is to develop value propositions or business cases for solutions to overcome these problems and prioritize them and define use cases. Then the team needs to develop a holistic digitalization approach for achieving operational excellence that addresses the selected use cases simultaneously. Not only will this eliminate duplicate or conflicting effort; it assures an optimum outcome. Furthermore, the team must determine the digitalization readiness as to where the company stands in the journey and what takes to achieve digitalization fulfillment for achieving operation excellence. A typical digitalization journey takes several steps as shown in Figure 1.8.

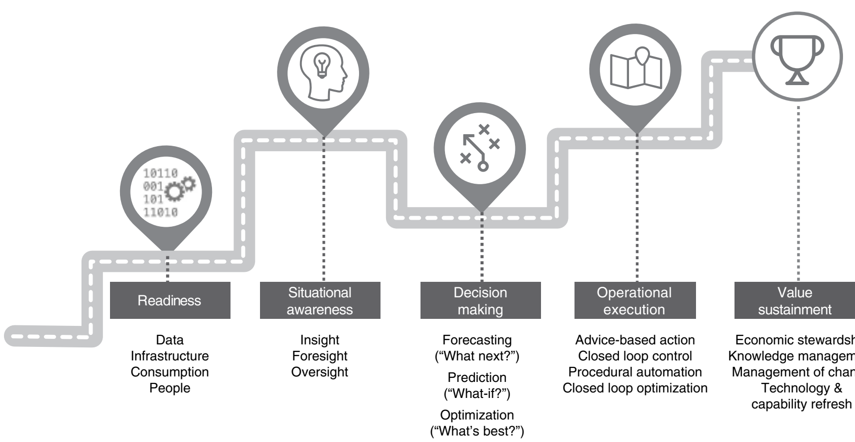

FIGURE 1.8. A typical digitalization journey.

1.7 OVERVIEW OF THE BOOK STRUCTURE

The challenges presented for industrial digitalization can also be viewed as opportunities—to grow, connect, streamline, and build chemical manufacturing value chain. However, the path to digitalization can be fearful to many people because of the changes that may involve and can be confusing at the same time for what steps that digitalization could take to implement and what values that digitalization could generate. This book will explain recent emerging technologies in the field of industrial digitalization and their implications. More importantly, the book will focus on the key enabler so-called Connected Plant and its applications.

What does the Connected Plant Performance (CPP) look like? In overall, the CPP adopts first principle models as the brain supported by data analytics and ML algorithms, digital twin as the foundation, IIoT as the data infrastructure, and cloud or edge as the platform. CPP connects processes, assets, people, and work processes. CPP allows effective cyber–human interactions where digital solutions provide intelligent indications and recommendations that enable plant personnel to act with agility and confidence to respond to threats and opportunities. A Connected Plant can see operations with a reduced number of unexpected events: excellent levels of reliability, safety, performance and environmental compliance, and assets running with extraordinary efficiency in terms of energy and process yield.

The Connected Plant is more than just data collection and software tools. It is about applying effective sensing, cloud computing, IIoT, and data analysis for revealing insights, process, and asset optimization and automation to address end-to-end customer touchpoints and desired outcomes. It creates value through real-time data analytics, models, and optimization, via revealing new insights for opportunities leading to turn-key solutions. It is about horizontal and vertical integration of different levels of activities, from business planning for feed and product selection at corporate level to operation planning and scheduling at the plant level and to process optimization and control at the DCS level. At the same time, applying Connected Plant results in faster detection and resolution of operating problems as well as more effective best practice sharing and knowledge management. For the first time, these aspects will be discussed and brought together in one single book, which covers the end-to-end execution of digital transformation—from leadership-level strategy to sensors, data analytics, process models, optimization models, data infrastructure, and integrated workflows and to on-the-ground team implementation for industrial companies. This is the main feature of this book.

The book will explain the principles and practices that lead to successful transformation to CPP: what are the gaps associated with traditional work process and how can the gaps be closed by applying Connected Plant concept. From this book, one can learn the following:

- How to create a digital road map and develop digital tasks?
- What takes to establish CPP?
- How to digitally enhance profit, reliability, operation, and control?
- How to integrate different levels of activities and then automate integrated processes digitally?

While many companies have looked at various ways for implementing digitalization, very few have taken the holistic view of applying digital transformation to close gaps in current business and technical processes. Digital solutions should be developed centered on the pain points or gaps identified with a clear perspective of prioritized opportunities and with the outcome-based approach. The book also share some successful applications to show the evidence of what some companies are doing to take advantage of industrial digitalization and to survive and thrive for now and in coming years.

The intent for this book is to break down the myth surrounding digitalization and data science.

This book describes how a new breed of real-time analytic solution enables continuous monitoring, optimization, and control of key plant operating conditions and allows for the earliest possible indication of performance degradation and the appropriate prioritization to address the situation. By taking advantage of advanced "digital twin" technology enabling the most advanced monitoring, analytical, and predictive capabilities, process engineers can implement around-the-clock monitoring of plant data and ongoing operational health checks and recommendations to close performance gaps.

To accomplish the above goals, the book comprises four parts with 20 chapters in total, and the structure of the books is explained as below:

- Part 1—Challenges and Opportunities, which consists of three chapters. An overview of industrial challenges, which defines the needs for digitalization, is provided in Chapter 1. The concept of Connected Plant to overcome the challenges is described in Chapter 2. Furthermore, Chapter 3 provides an overview of data science for industrial applications.
- Part 2—Data Analytics for Smart Operations, which consists of seven chapters. In this part, individual modeling techniques including first principles, statistics, optimization, AI and ML are discussed in details. Intelligent models can empower digital solutions to convert data to new insights and actions.
- Part 3—Connected Plant for Smart Operations, which includes six chapters, which focus on individual components of Connected Plant ranging from asset and safety management to integrated planning and control, from workforce enhancement and workflow management.
- Part 4—Digital Solution for Smart Operations, which includes four chapters. In Part 4, the data infrastructure and open architect for the digital solutions is discussed. Furthermore, digital readiness assessment for industrial companies is explained, and an effectivity digital journey is described with a roadmap showing signposts of milestone progress. Finally, application case studies are provided to share the success stories in applying digital solutions for operation excellence.

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