RETROFIT PROCESS PLANT DIGITALIZATON

Digital Transformation

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Preface

Retrofit Process Plant Digitalization is a series of articles on Digital Transformation in the Process Industry. Most of these articles are transcripts of my presentations at Universities, Conferences/Trade Shows, or Webinars during the past three years. As my 2020 travel came to a halt, I decided to put these scripts in the hands of my marketing team at IntelliFlux Controls as precursors for their marketing writeups. I initially thought that our marketing experts will consider these quite dense (none of my writeups get a Flesch Readability score above 30). I was surprised when they suggested I post them on the Company Website as "position papers" or "thought articles". Well, as long as these are not printed on paper, and it only hurts electrons to transmit these, I am not averse to posting these. I hope that someone in the process industry, and anyone interested in exploring digitalization, may find these articles informative. I hope that professionals facing challenges with digitalization or grappling with the digital transformation drive around the world will find nuggets of interest in the experiences I share about retrofit digitalization.

The present article "*Digital Transformation*" outlines the benefits to be gained by the process industry from a planned digitalization initiative. We have rarely seen process industry experts and leaders having a clear consensus about what digital transformation entails, what are the key improvements that can be brought about through digitalization, and how to measure the benefits of digitalization.

The first step toward digital transformation of your process plant is to understand what digitalization and Industry 4.0 entail, and what is the difference between the digital layer and the already existing plant automation framework that exists at your process plant. The process industry already has a digital automation infrastructure in place. Therefore retrofit digitalization may not be too onerous for this industry. The key aspect of a successful digital transformation is to make your plant data work for you in a manner that is more effective and smarter compared to the data that you already gather and use at the plants.

I am grateful for the tremendous support from IntelliFlux Controls, our stakeholders, our customers and well wishers. As the founder and CEO of IntelliFlux Controls, I do see everything through the lens of my IntelliFlux journey. So, my technical writeups cannot be strictly classified as "impartial and academic" anymore. That said, I still appreciate the freedom my company gives me to write the way I like to write – objectively. Finally, if there are any errors or omissions in this article, the responsibliity is entirely mine.

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Digitalization and Process Automation

What is digitalization[1]? What are smart plants? To answer these questions, it may be pertinent to discuss the principles of Industry 4.0[2], the new wave of industrial digitalization garnering attention since 2013 as the fourth wave of industrial revolution (Figure 1) [1-3]. At the heart of this is the concept of smart factories, that will adopt information and communication technology in its existing instrumentation and control framework. This will lead to an evolution in manufacturing that brings a much higher level of both automation and digitalization. Such automation will enable machines to self-optimize, self-configure, and utilize learning algorithms and artificial intelligence (AI) to optimally perform complex tasks without human intervention. Such advancements will deliver superior cost efficiencies, enhanced reliability of operations, and improved quality of goods or services.

Industry 4.0 envisions the use of Internet of Things (IoT) and cyber-physical systems such as sensors, actuators, vision systems, and robotics to collect and use plant information in a real-time manner by manufacturers to increase production efficiency. The core technical implementation of Industry 4.0 centers around the Physical-to-Digital-to-Physical (PDP) loop. The PDP loop involves

(i) collection and mapping of sensory data from a physical plant to a digital realm,

[1] 'Digitalization' and 'digitization' have been used interchangeably in literature. In this article, we will use the term digitalization to refer to digital transformation of process plants, without getting into the argument regarding what is correct nomenclature.
[2] The original terminology used was 'Industrie 4.0' in the earliest documents on this topic. In this article, we will use the term 'Industry 4.0' to imply 'Industrie 4.0'.

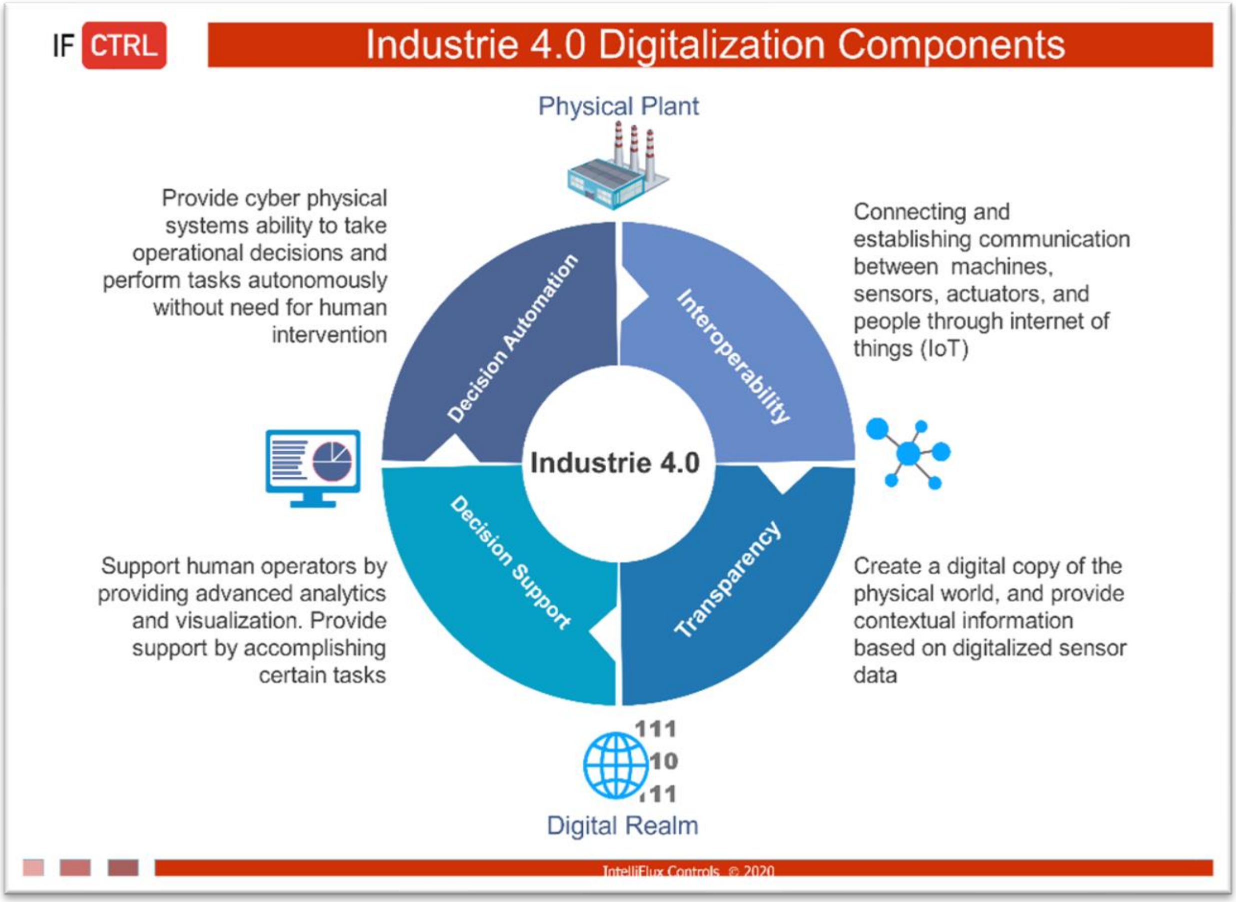


Figure 1: The concept of Industry 4.0 digitalization.

(ii) performing analysis at various levels of complexity in the digital domain, including basic statistical analysis, correlations, predictive analytics, and deep learning, followed by

(iii) transmitting the assimilated information from the digital realm back to the physical plant for actions to optimize and enhance the performance of the plant.

Advancements in communications protocols and technology, computation, big data, augmented reality, and powerful analytics enables realization of such a vision.

Industry 4.0 is based on four fundamental design principles (Figure 1): Interoperability, information transparency, decision support, and decision automation.

- ***Interoperability*** is the ability of machines, devices, sensors, and people to connect and communicate with each other through the Internet of Things (IoT).

- ***Information transparency*** provides information systems the ability to create a virtual copy of the physical plant and enriching the digital plant models with sensor data. This requires the aggregation of raw sensor data to higher-value contextual information.
- ***Decision support*** pertains to technical assistance. First, it provides automation systems the ability to support operators and engineers by aggregating and visualizing information comprehensively for making informed decisions and solving urgent problems on short notice. Second, it physically supports operators by conducting a range of tasks that are unpleasant, repetitive, too exhausting, or unsafe for humans.
- ***Decision automation*** provides plants the capability of making operational decisions on their own and to perform their tasks as autonomously as possible. Only during serious exceptions, interferences, or conflicting goals, are tasks delegated to a higher level for human intervention.

This article explores how digital transformation can be effectively achieved for the chemical process industry. In this context, it is pertinent to define chemical process plants and why digitalization of such plants should be considered as a special case of manufacturing. Chemical process industry broadly encompasses the manufacturing of products involving handling of fluids (liquids and gases), granular solids, chemical reactions, molecular separations, and phase changes (evaporation, boiling, freezing). Examples of chemical processes are manufacture of essential and specialty chemicals, cosmetics, fertilizers, food and beverages, mining and extraction of minerals, materials processing, nuclear power, pharmaceuticals, polymers and plastics, paper and pulp, petroleum extraction and refining, production of pure gases (such as oxygen), semiconductors, textile, and purification of water (such as desalination of sea water or treatment of wastewater), to name a few. These plants usually process materials that flow - and are transported through pipes, conveyors, or stored in tanks and pressurized containers. These plants often contain reactors that convert chemical species, producing or absorbing heat.

In sharp contrast with many mechanical manufacturing operations in the automotive, electronics, and various assembly based industrial sectors, chemical plants do not usually deal with discrete objects. They do not usually involve cutting, rolling, turning, milling, fitting, joining, or metal forming as core actions. Chemical processes are usually not monitored visually, but through parameters like pressure, temperature, flow rates, chemical signatures (spectroscopically), ultrasound propagation, radiation, etc. Defect of a chemical process or a product is not solely manifested through optical monitoring of dimensions form or shape, but through more abstract measurements of composition, density, rheology, surface properties, etc. Hence, special consideration is needed to map concepts of physical to digital transformation, digitalization, and process automation for chemical process plants.

Considerable attention has been directed toward digitalization and robotic transformation of mechanical manufacturing and assembly. In contrast, the paradigms of digital transformation are far less evolved for the chemical process industry. Fortunately, the subject of process control has matured tremendously over the past six decades in the chemical processing industry, and many components of digitalization were already embedded quite solidly in the chemical process industry. Autonomous control, handling of complex reaction dynamics, cascaded control, non-linear control, fuzzy control, multiple-input-multiple-output (MIMO) control, and even artificial neural network based optimal control have all been quite widely adopted in various segments of the chemical process industry. A lot of these processes are already quite smart. Therefore, the chemical industry is possibly one of the best poised to leap forward with respect to realizing the full benefits of digital transformation and smart manufacturing.

Considerations for Implementing Digitalization to Process Plants

A modern digitalization architecture can be readily constructed in a **top-down** manner for a new chemical process plant. Such an effort can embed all the features and advanced capabilities of modern digital communication, computing, and automation technologies by specifying the necessary hardware and software components in a synergistic manner. However, **to implement digitalization as a retrofit upgrade to an existing plant, one cannot readily envision a top-down approach, since it is expensive, time consuming, and disruptive to the operations of the plant**. Such a capital infusion on older and depreciating plants may not be economically viable.

Retrofit digitalization requires building on the existing automation framework of the plants. This **bottom-up** approach requires a thorough understanding of the processes and automation steps of the existing plant. This assessment of the existing control and automation framework of a plant is important to avoid conflicts between the existing framework and the new digitalization systems to be implemented. Such conflicts may manifest as redundancy, impaired reliability, and security. A thoughtful investment in this bottom up approach of implementing a digitalization retrofit can significantly improve capacity utilization, efficiency, reliability, and sustainability of existing process plants.

To implement a bottom-up digitalization framework, an important consideration is to assess the capabilities of your plant's existing automation framework, clearly articulate the goals to be achieved by the added digitalization features, define key performance indicators (KPIs) and metrics to measure success, project expected returns on investment (ROI), perform a gap analysis, and then embark on an improvement plan. Fundamentally, you have to first ask: ***"What additional benefits does digitalization offer that is not already provided by my current plant automation layer?"***

Let us now assess how the four key concepts of digitalization, namely, interoperability through internet of things (IoT), transparency, decision support, and decision automation, can be implemented in existing process plants.

Interoperability

Technically, networking was integral to process control systems since the inception of distributed control systems. However, in the past, networking a process control layer with even the business communication network, or the broader internet domain was mostly discouraged owing to the perception of security threats. Connecting the automation layer to the internet was never a technical challenge since the inception of the Internet. One may argue that the communications protocols embedded in the instrumentation and automation layers of the industrial network preceded the Internet. The internet protocol (IP) only provided another communication protocol for the machines, and broadened the horizon of industrial communication outside the realm of the plant or factory floor.

It was the cybersecurity threats posed by the internet, and policy frameworks put in place to mitigate such threats - that created, and continues to create, barriers toward widespread implementation of internet-based connectivity and interoperability for industrial automation. Industrial Internet of Things (IIoT) and connected infrastructure through wired, wireless, cellular, and even short-range wireless protocols (e.g. Bluetooth) have two ramifications. First, the plant operations and management will need to manage their cybersecurity protocols and standards by considering additional conduits of information that interface with critical assets and operations. Second, diverse modes of communication protocols can be brought into the plant floor, sometimes bypassing the existing core architecture of the process automation framework in these plants.

Transparency

A process plant employs a sequence of operations or processes that work in tandem. Information transparency is viewed by many as myriad sensors added to these diverse process components at a plant to provide information to a data silo and computational framework. The information can be processed and compared against a digital model or a digital twin of the entire plant. With powerful computing, it is possible to conduct this comparison dynamically, providing improved ability and insight to assess how the actual plant is behaving *vis a vis* its digital model. This is where machine learning algorithms can be deployed to analyze and correlate the plant operational data to provide better understanding of the plant and control their behavior effectively.

Such a framework is attractive for centrally managing multiple operations at a process plant, or even managing multiple process plants from a single focal point. This information transparency between multiple plants was also available in some classical SCADA networks (power generation and distribution through a smart grid being a classical example), although its implementation in other segments of the process industry sector has been less widespread.

Decision Support

Decision support has also been around in context of classical SCADA systems for quite some time. The business model implemented until recently was a back-end support of the plant operations through call centers which would aggregate, correlate, and analyze plant data, and would alert operators or technicians at the plant through text messages, emails, or phone calls when certain trends and alarms were triggered. The issue with many industrial processes is that human intervention is required constantly, and notwithstanding lightning fast transmittal of data and high-powered analytics, deploying the results of such analysis into the realm of process intervention in a time sensitive manner remains a bottleneck.

Decision Automation

Decision automation involves closing the PDP loop between collecting and correlating a wide range of data from plants through IoT, processing them to understand the relationships between the different process operations, and taking the results of such analysis to deliver automated (and autonomous) timely interventions to a process, while providing the human operators and stakeholders the necessary information and visibility of the process performance. The use of decision automation can truly realize the full benefits of digitalization in the process industry. However, this is the poorest implemented segment of digitalization in the process industry, and an area where key bottlenecks exist.

Someone familiar with process automation and control, particularly the advanced control paradigms of cascaded control, multiple input multiple output (MIMO) control, non-linear control, optimal control, and fuzzy logic implementation will probably wonder what is the difference between decision automation and these advanced process control constructs. Superficially, the answer is probably “nothing”. However, one should dig a bit deeper into the current state of automation implementation in the process industry to realize how harnessing the power of internet and distributed computing can enhance the deployment and effectiveness of these complex process control constructs. Bringing in decision automation to process plants is not terribly complex, and decision automation is certainly not a new concept in process control. However, the efficiency with which modern computers and communications frameworks can deliver these, and their present-day cost points make them accessible to the process industry at an unprecedented price and value.

A key factor that creates barriers toward implementation of decision automation in process plants is the knowledge gap between the process experts who traditionally program and operate the plants, and the software developers who are deploying the modern digitalization platforms. The process engineers and operators typically do not realize the additional process information they can gather from digital transformation over what they already have through their SCADA system. They often view the decision support systems as extensions of their SCADA historians and dashboards, and rarely delve deeper into the convolutions, correlations, and transformations of datasets to extract deeper insights regarding the processes. Conversely, the players in the digitalization business are not prepared to undertake the entire risk of automating the plants and processes by closing the PDP loop, partly because it involves undertaking liabilities and providing process guarantees, and partly because the path of how to control the individual process elements is not clearly charted out. In this context, the majority of the implementations of digital transformation in the process industry are often restricted to comparison of the plant operating data to process models (digital twins) through regression. In some cases, these lead to some improvement in feedback control mechanisms or better maintenance.

Digitalization purports to making manufacturing "smart", and this has already been implemented in several manufacturing sectors (automotive, for instance). However, for the process industry, where one deals with fluids, complex chemical reactions, phase change physics, and intricate multi-physics dynamics between reactive material and energy flows, such smartness is not readily built into the operations. There are certain Achilles heels of the existing automation framework of process plants that hinder a simple implementation of the full extent of digitalization. Part of this fundamental problem rests on how our current automation framework is programmed, specifically in the programs and codes that run and control our process plants today.

Implementation of Industry 4.0 in Brownfield Plants

Adoption of Industry 4.0 concepts in process industry operations will grow by strides over the next decade. Sensors, information flow, advanced automation technologies, and advanced software that embed digital twins, machine learning, and artificial intelligence - the digital and physical technologies enabling Industry 4.0 - will make it possible to access real-time information and insights throughout an organization to improve operations, enhance productivity, and deliver cost savings. Digitalization will enable process industries to accomplish complex decision-making in a transparent and entirely new way, potentially revolutionizing supply chains, production, and business models. Applied to brownfield plants and manufacturing assets, the steps outlined in the sections below can ensure such a transition toward digitalization.

Assessment of the Existing Plant Automation Status

Implementation of Industry 4.0 principles to existing (Brownfield) plants is not a trivial undertaking. Plants designed and built in the past, and many plants that are operating today, were not built with digitalization, autonomous process optimization, or remote communication and control in mind. Some digitalization enthusiasts envision completely overhauling the entire automation hardware/software framework at these plants to implement compliance with Industry 4.0 design objectives. Building a brand-new digital layer by replacing the existing automation infrastructure can be cost prohibitive, and extremely challenging, if done in an *ad-hoc* manner. This approach appears to be difficult from a purely economic perspective, as such a digital retrofit on an old plant with a lower residual life expectancy compared to a brand-new plant will inevitably yield lower returns on investment (ROI). Implementation of such a solution will also disrupt the normal operation of the plant during the retrofit. It is therefore imperative that the state of the existing automation framework at the plant is considered when embarking on a digitalization strategy.

Appendix 1 shows a sample of a typical questionnaire that allows one to assess the digitalization readiness of a plant pertaining to the automation infrastructure (this specific example applies to a wastewater treatment plant). This assessment of the baseline automation level at a plant can lead to the development of several digitalization strategies that are economically viable, practicable, and sustainable. With this baseline assessment done, industries with existing plant infrastructure should next focus on stepwise implementation of Industry 4.0 design principles, and make small, but decisive steps toward digitalization.

Experimentation and Evaluation

Explore the potential benefits of various digitalization component technologies and their potential impacts on the plant operations, and the overall value it will accrue for the business. Create proper evaluation metrics for each component technology, and work through case studies and demonstrations that clearly indicate the benefits of such additive improvements on the overall plant operation. Such experiments are preferably conducted on the plants and assets on which digital transformation will be applied. A serious pitfall in retrofit digitalization is to adopt a solution that probably worked at another plant but does not fit the process or plant under consideration. Blindly copying a digital implementation from one plant to another can yield quite unsatisfactory results.

Frequently, we have seen process industries and plant owners believe that digitalization implies adding sensors and linking them up as internet of things (IoT) objects. This leads them to add sensors of every conceivable type to their plant without properly accounting for their relevance to the process and their benefits. While additional sensors do put more information at our disposal, there are several problems that immediately arise:

(i) Operators need to be trained to use and maintain the new sensors,

(ii) There is no clear understanding of how the sensor adds overall value to the process, and how it enhances the overall utilization of information for profitability,

(iii) When the sensors do not provide the desired benefits, it leads to the notion that digitalization has no value.

The key lesson here is that sensors and IoT are just one small component of digital transformation. Simply adding sensors to a plant or a process cannot lead to an overall attainment of the benefits of digitalization. It is important to understand what maximizes the business' benefits of digitalization, how each additional automation component injects efficiency into the workflow, and start to take steps that are the "lowest hanging fruits" to attain a successful digital strategy implementation.

Building an Ecosystem

Assess the organization's digital maturity to understand what might be feasible, and what steps should be taken to build the necessary technological capabilities with the resources that are already in place, versus what new resources might be needed to achieve the digitalization goals. Beyond the technologies themselves, consider the expert resources you may want to cultivate, either externally or internally, as part of your Industry 4.0 implementation strategy.

The process plant is a component of your entire business, and digitalization of such plants should be implemented following the overall digitalization framework for the entire business. Therefore, an assessment of the existing business automation framework of the organization is critical before embarking on digitalization of the process plant. This requires assessment of what are the organization-wide strategies of networking and automation, what enterprise resource planning strategies and systems are in place, how information flows across different sections of the business, what is the organizational structure, what are the information security management systems (ISMS), and how the plant and process operations information can be integrated to add value to the existing business informatics framework.

Scaling at the Edges

At times, it makes sense to start with smaller stakes, where strategies can be tested and refined with relatively fewer consequences. Selecting projects at the "edges" of the organization can provide greater latitude for building out Industry 4.0 at a broader scale and can also help individuals feel less afraid to fail, which could ultimately lead to greater innovation.

In this context, process industries can start implementing digitalization selectively to ancillary processes such as water and waste management, energy management and recovery, maintenance of smaller plant components, inventory systems, and operations management systems, allowing them the ability to test the success of digital strategies in these sections without affecting their core production process. Implementing digitalization to the entire plant can be a major undertaking and quite disruptive to normal operation.

Proving with Strategic Implementations

It is important to prioritize areas that can unlock several waves of potential value. Building on those successes for sustained growth, where the initial successes can serve as proof points, will lead to a greater willingness to build momentum toward more substantive investments.

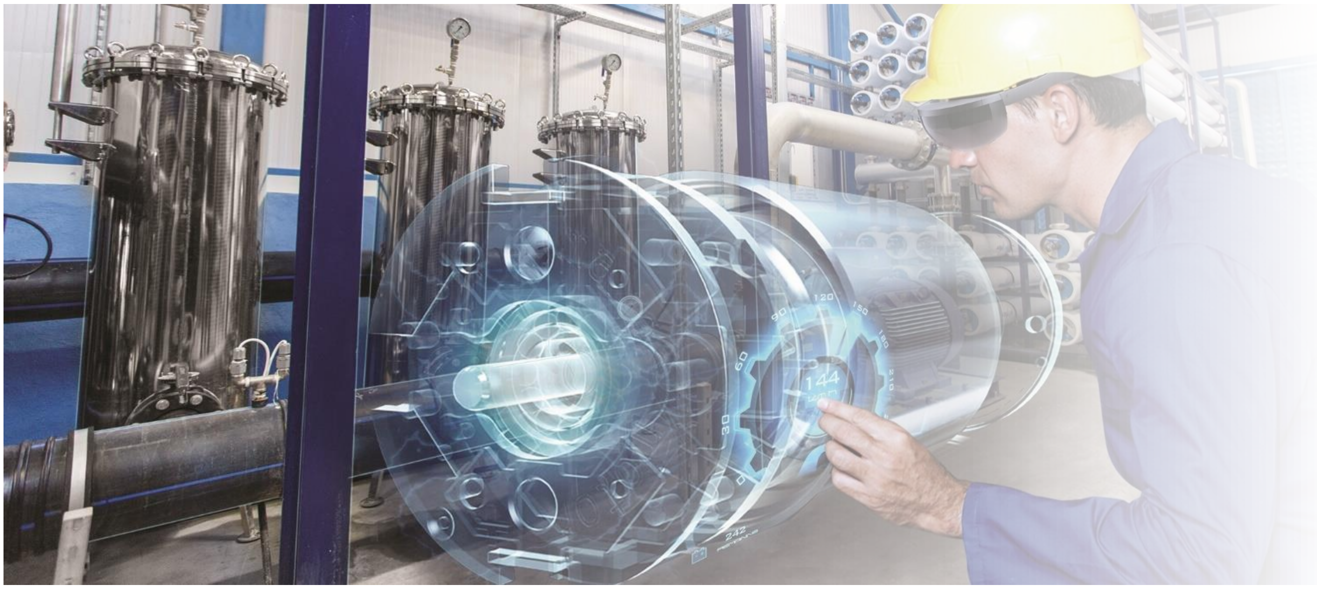
Not all aspects of digitalization are readily implemented in every project. Digitalization can also provide different value propositions to different processes. Assessing every implementation of digitalization through the same lens or through the same set of key performance indicators may lead to misconceptions. The most important aspect of digitalization is to impart to process plants the ability to adapt and take autonomous decisions, provide predictive guidance to the plant personnel, and assist with avoidance of downtime. The benefits of such an initiative cannot be simply assessed through accounting of single metrics, such as energy savings, water savings, reduction in labor, increase in uptime, enhanced productivity, or better visuals and dashboards for the plant's operations team. Rather, digitalization entails a combination of all of the aforementioned factors, and more, leading to the company changing its operational culture around how the plant is maintained and managed, helping with the overall sustainability and reliability of the business.

Utilizing proper metrics to assess these cumulative benefits is extremely important. The definition of these success metrics requires amalgamation of multiple stakeholders' points of view for the process. The digitalization and automation stakeholder would measure the performance of the solution through the types of information shown on the dashboards, and the utility and timeliness of predictions provided by such systems. The sustainability stakeholder will evaluate the success of the digital solution through the savings of energy, water, GHG emissions, and other related metrics. The operations team would consider the benefit of such solutions in terms of streamlining preventive maintenance, or through alerts and alarms that help avoid downtime, or timely alerts for process component maintenance scheduling, or even the ability of remotely monitoring and controlling the plant. The reliability stakeholder will possibly measure the benefits of the solution in terms of avoidance of downtime, increased productivity, and risk mitigation through prevention of failure or disruptions. Finally, all these different perceptions of the digitalization initiative's value need to be aggregated for the corporate management level stakeholders, boiling them down to the critical parameters of profitability and investor value accretion.

Iterative Improvement

Industry 4.0 technologies are evolving rapidly. Certain components of digital transformation are still at their early stages of development. In this context, adoption of these technologies in our existing brownfield process plants can provide us tremendous opportunities to test what works and what does not, and there is typically room to iterate. Learning from previous experiences can inform the future initiatives.

Our retrofit digitalization efforts with existing plants are helping us create enormous databases of how these plants operate, how external factors (such as seasonal changes, influent conditions, operating practices, etc.) affect their operation and efficiency, and in many cases, how problems encountered by these plants and processes can be avoided through improved design. Digitalization of existing plants can provide improved design paradigms for the upcoming plants and plants of the future. This is possibly one of the biggest and most overlooked benefits of digitalization, that is, it forms the underlying cornerstone of life cycle design. Iterating on the implementation of digitalization, attempting to transform the existing process plants to smart plants with today's digital technologies can lead to the development of fully integrated technologies building the smart plants of tomorrow.



Challenges in Implementation of Industry 4.0:

When adopting a digitalization strategy, one should be aware of the numerous challenges it will pose, particularly for a brownfield application. The three key challenges that top the list are: (i) Exposure to cybersecurity threats, (ii) Misconceptions from lack of technical knowledge, and (iii) Lack of understanding of management changes arising from digitalization.

Cybersecurity

The most pertinent of these challenges is the aspect of ensuring cybersecurity. Many sectors of the process industry are quite sensitive about transmission of process, production, and plant performance information over the internet. Classically, many sectors of the process industry used a quarantined network for the plant control systems – referred to as the control local area network (LAN). The control LAN was separated from the company or business LAN. Specific connections were allowed between the business and control LAN using concepts like de-militarized zones (DMZ) and firewalls. Classical communications protocols within the control LAN were also restricted to MODBUS, PROFIBUS, or TCP/IP, which were isolated from conventional internet protocols.

With the advent of numerous communication mechanisms (cellular, wireless, Bluetooth, etc.) that constitute today's industrial internet of things (IIoT), one must be particularly careful about how information flows between the plant environment to the business environment. Breach of security can easily occur if any external user or device from outside the plant gains unauthorized access to the process control system. This can have catastrophic consequences.

The interconnection between systems is a key feature of Industry 4.0, implying that there are more devices connected to the Internet of Things. This represents a massive cybersecurity challenge in terms of data protection and intellectual property. Robust security systems and protocols to protect against hacking and unintentional data breaches are a pre-requisite toward the implementation of any form of digitalization.

Policies, processes, and procedures should all be standardized to limit the amount of possible breach points in the modified digitalization framework. New policies are being constantly implemented. In this regard, use of the IEC/ISO 27000 [4,5] framework should be minimally required as a standard cybersecurity policy. In the USA, cybersecurity assessment and policies that minimally adhere to NIST guidelines [6] should be implemented.

Technical Understanding

Developing a proper system level understanding of how to interface process engineering with automation, instrumentation, information technology, and computation (hardware and software) that are all at the cutting edges of their respective technology silos is no mean task. There is no single discipline that can be considered as a single driver of digitalization. All of these disciplines play an equally significant role.

It is certainly an overstatement when claims are made that process related knowledge is not needed in a smart plant because the artificial intelligence (AI) can “figure out the underlying process dynamics from the data”. Such statements immediately expose the lack of understanding of what the various AI and learning algorithms are capable of.

Similarly, when proponents of automation state that with digitalization, plants can run themselves without requirement of human intervention, we immediately see a chasm between the state of the art and science fiction. Even in today’s most automated plants, the manufacturing process is carefully managed and orchestrated through human effort and interactions. Human intervention is required minimally in such plants at two levels – at the top level, with respect to process definition and goalsetting, and at the support level, where components need to be replaced, consumables need to be replenished, and repairs need to be made. With machine learning introduced at these plants, another task that will become critical for humans will be to train these algorithms.

Proponents of sensors and IoT who come from the data science (digital) side often make impractical assumptions about how the physical components of a sensor or transducer should operate. A common mis-conception we observe in many applications is how a pH or a chemical sensor is wired up to acquire data every 30 milliseconds, whereas the physical device itself requires at least two minutes to equilibrate and yield a single meaningful reading. The result is misrepresentation of data and a lot of downstream data filtering and noise cancellation. We have seen machine learning algorithms being fed incorrect vacuum pressure data that stem from a trivial misunderstanding of gauge pressure and absolute pressure, and hence, such algorithms, when deployed in their predictive capacity, could incorrectly set up dangerously high pressures for a filtration system. We have seen cameras being deployed to acquire information about liquid flow from nozzles, which are then processed using convolutional neural networks (CNNs) to provide an estimate of the flow rates and indicate malfunction of the nozzles. Apparently, there was no instrumentation, mechanical, or process engineering expert in the project who could point the project team to a flow or pressure sensor.

Each of the above examples, when presented to a team of engineers or professionals with different backgrounds, will elicit laughter from only one or two members of the team – persons with the appropriate background to understand the problem. Someone understanding the chemistry and kinetics of the pH sensor will know why pH measurement data collected at millisecond interval is meaningless. Someone with understanding of gauge pressures and how vacuum or differential pressure transducers work will immediately understand the potential problem with incorrect use of gauge pressure. The final example of using cameras for flow sensing may elicit laughter from a broader group of professionals as they will see this as a mechanism of testing the algorithm by force fitting the physical data to the requirements of the algorithm (the classical hammer looking for a nail problem). The CNN algorithms were developed originally for pixilated image data – and are the most widespread implementations/examples of the technique.

A similar gap exists when process engineers and process control experts encounter the modern digitalization and AI wave. A clear understanding of what a "digital twin" signifies is generally lacking. A digital twin is simply a mathematical model of the process that captures its essential physics. Furthermore, it is often unclear how well the process engineering experts understand and assess the use of the broad term AI, when they are exploring AI solutions for their plants. In implementations of decision-making with so-called AI driven algorithms, we were often surprised to find the use of the "if-then-else" construct as the highest level of algorithmic intelligence. Even a run-of-the-mill moving average crossover (MAC) algorithm, which is the staple of financial market forecasting (I would have reservations against this algorithm as a robust forecasting tool) is difficult to find in these artificial intelligence deployments. The issues with process control using AI starts even before one gets to the algorithm - with the data itself. First and foremost, many of the commonly used deep learning and artificial neural network algorithms, as well as classification, correlation, and regression methods are not best suited for time series data. The ones that work with time series data generally require equally spaced time intervals. So, when time series data is intermittent, one must put considerable effort to render such datasets useful for training the AI algorithms. There are significant issues with data in the process industry because different types of temporal process data are acquired at different frequencies (time intervals). Different parameters in a process plant can have widely different magnitudes, and an essential pre-requisite for large volume data processing is proper scaling of the data. This is often disregarded in many implementations. Finally, we often do not realize that sensors suffer from getting dirty or drifting from their calibration settings over time. Therefore, sensor fidelity is an essential component of robust digitalization systems. Little progress has been made in this regard in the process industry. Lack of proper communication/coordination between the process expert, the instrumentation professional, the data science expert, and the AI algorithm expert can lead to significant issues about the reliability of any digital solution.

Misconceptions about what digitalization and AI can achieve often lead to impractical and unrealized expectations from a digitalization exercise. This is particularly true for a brownfield process plant. Neither will the old plant become shiny and new with digitalization, nor will it be converted to a magical new plant. Digitalization will only provide results comparable to most other plant debottlenecking options. Digital transformation will improve its performance over what it was experiencing before digitalization, and although the plant depreciation profile following digitalization will change, it will not stop depreciating altogether.

The above factors point toward a systemic problem that has magnified over the past few decades – the lack of a system level knowledge that encompasses all the disciplines involved in a modern industrial production scenario. All the industrial operations and technologies have become more complex. It requires a multidisciplinary team of experts to solve any problem. And this system engineering approach is only practicable in the execution of large projects with huge capital investments deploying coordinated efforts of a multi-disciplinary team. Large organizations deploying turnkey industrial systems are becoming agglomerated and growing even larger as they have the resources and magnitude to accost the complexity. The future of technology will mainly consist of businesses that can deal with complex systems.

While digitalization is being implemented in many organizations and sectors of business, a key question becomes, what internal capacity building, retraining, and changes will be needed in these organizations to enable them to handle and properly capitalize on the benefits of the digital transformation.

Change Management

Digitalization efforts are being heavily focused on the processes, plants, and machinery, while largely ignoring the human elements. However, the communication between humans and machines is an important tenet of digitalization. For the foreseeable future, and certainly for the brownfield plants retrofitted with digitalization, the human element will be an important component of digitalization. This gap in understanding the importance of the human element is creating problems in many industries.

The first perception of digital transformation in most societies is the anxiety it imparts regarding loss of factory jobs. Historically, automation in the process industry has resulted in elimination of many plant floor jobs. However, this has been construed as less controversial in the process industry compared to several other manufacturing sectors, since many process plant jobs were hazardous, and led to human casualties. In many sectors of the process industry, the number of on floor person hours required per unit of production throughput is one of the lowest in the manufacturing sector. Most of the operational workforce in process plants is primarily the process engineering and operating team. Therefore, digitalization does not seem to be an immediate threat to process industry jobs. However, adoption of digital technologies will gradually change the roles and responsibilities of many of the existing process plant employees.

The most significant change that we observe in process plants after digitalization comes from the ability of the plant operations teams to monitor the operation remotely. This leads to many modifications in how the process operations team can readjust their schedule. Digitalization practically untethers the operations team from the plant floors by giving them the ability to keep an eye on the plant from anywhere, anytime. This change is like what might have happened in the medical sector with the incorporation of pagers and communications systems. With pagers, the doctors and specialists did not anymore need to do the rounds or routine shifts to continuously monitor the patients, but were on call whenever necessary, and were able to attend to the needs of the patients, which could arise anytime round the clock. This same paradigm can be seen in process plants with a properly implemented digitalization framework. The engineers and operations team members can ensure smooth operations of the plant, and even deploy the necessary support whenever the automation system indicates the necessity of human intervention. This can allow adapting to the evolving cultures of working from home or remote working that we see in other sectors, instead of forcing a large workforce to remain on the plant premises for a stipulated number of hours on a shift. With appropriate tools, such remote working cultures can indeed be incorporated into the operations regimes of the process industry.

A major shift we observe in process plants post digitalization is how the plant operators, equipped with a global view of the plant performance, change many of their operations management practices. Before digitalization (particularly before implementation of the interoperability and transparency elements), individual support personnel were assigned for specific process components. Their roles were to only maintain the performance of a single piece of equipment, their visibility being restricted to the inputs, operating conditions, environment, health indicators, and effluents from the sole equipment they were responsible for. Post digitalization, when the operations team gains real time visibility of every detail of the entire plant, they can integrate information from a broader range of parameters (such as performance of an upstream equipment, or quality excursions in the raw material feed) to manage the individual equipment and processes. This improves the team dynamics, and allows the operators to achieve global optimization, more effective and timely interventions, preventing many cascading failure events in production.

Digitalization of Process Industry Through the Lens of IntelliFlux Controls

IntelliFlux Controls has implemented its digital transformation stack in many process plants around the World within a cross-section of the chemical process industry. This allowed us to assess the complexities involved in digitalization of existing process plants. Our involvement has ranged from sensor specification and placement, to augmenting the supervisory control and data acquisition (SCADA) system, to implementing various forms of decision support, and in some cases, implementing decision automation to dynamically optimize the plant. We have analyzed the multilayered industrial automation architecture of the plants, evaluated the speed and reliability of communications protocols, data encryption, transmission and storage, efficacy of analytics and AI algorithms, and cybersecurity constructs. Our approach has always started with the baseline plant and process assessment for every brownfield plant, following which the best practicable digital transformation solution was prescribed for the plant.

Baseline Plant Assessment

One of the first tasks we perform for any plant is the **Plant and Process Digitalization Assessment**. While this assessment primarily considers the process automation layer architecture at a plant, it is closely integrated with the assessment of the process through evaluation of the original plant and process design, equipment details, process and instrumentation diagrams (P&ID), dynamics and kinetics of individual processes, existing automation hardware such as sensors, actuators, and the control components, and finally, the existing codes of the plant. This focus on the process engineering details along with the automation and distributed control system (DCS) features of the plant provides us a unique ability to clearly quantify the potential improvements that can be achieved with digitalization at each plant. We have already discussed one component of this assessment earlier, with Appendix 1 showing a sample questionnaire to review and score the baseline plant automation architecture.

Figure 2: Comparison of the digitalization state of two process plants, showing how the critical digitalization components are positioned before (blue) and after (red) installation of IntelliFlux.

It is quite fascinating to consider how different plants (even for the same process) are designed and how their retrofit digitalization readiness can vary. It is also interesting to note how much improvement can be achieved by IntelliFlux through a predominantly software-based digitalization upgrade. Figure 2 compares the automation architecture of two plants before and after digitalization. The radar (spider) charts measure eight key parameters related to automation level and digital readiness between a score of 0 to 5, zero being poor, and 5 being the highest level achievable. The dark blue colored lines show the status of each plant before digitalization (baseline), whereas the red colored line shows the state of the plant after a retrofit digitalization by IntelliFlux. The business case of our analysis primarily focuses on the economic gains of digitalization and ROIs achievable at each plant.

In the cases shown in Figure 2, the process control and automation framework of the plants were about five to eight years old. While the programmable logic controller (PLC) codes generally implemented the automation strategy quite adequately, the plants were not programmed to adjust setpoints or institute any operational changes in response to sensor data. None of the plants had any high-level control functions ascribed to the SCADA system barring providing the operators some ability to adjust process setpoints. Any change in process set points were done by operators. There was no scope of deploying smart plant paradigms, automated process optimization, or adaptive control through the existing programming architecture.

In most cases, reviewing and utilizing the PLC codes allowed us to construct a fairly accurate digital twin of the process, which can be refined further during digitalization and with availability of more operating data. Availability of the PLC / SCADA codes also allows the implementation of many decision support and automation steps quite easily. In one of the plants, although the basic SCADA framework was well developed, the elements of decision support were practically non-existent. When a plant had any problems, the SCADA system was primarily utilized for its historian, which provided the historical data for post-mortem analysis by a process engineer or consultant. The following list highlights our salient experiences with digitalization of process plants so far. Every plant we have retrofitted differed in its baseline automation layout, reflecting multiple combinations of the following factors:

1. Widely varying processes, operating cultures, standard operating procedures (SOPs) and practices, including operational priorities.
2. Different level of automation in similar plants and technologies.
3. Diverse range of sensors, with different protocols for connecting to the automation framework.
4. Widely varying pre-conceptions and pre-dispositions about digitalization, its benefits, risks, and consequences.
5. Strong leaning toward operator mediated process interventions, and mistrust of autonomous control.
6. Different brands and capability limits of programmable logic controllers (PLCs).
7. Different PLC programming languages, interfaces, and programming practices.
8. Different communication protocols between the various layers of automation (MODBUS, PROFIBUS, TCP/IP, OPC).
9. Non-existent to quite sophisticated SCADA hardware and software.
10. Different regulatory and cybersecurity frameworks (such as “air gaps” and segregation of business and control networks, use of firewalls with different settings, etc.).

With all these variables, one might be inclined to think that replacing the entire existing automation hardware hierarchy in a plant with a modern digitalization framework is more desirable. However, the existing plants had an automation strategy already in place, most of the automation hardware are perfectly functional, and through the PLC/SCADA codes used to program them, there is a fully working blueprint of the operational philosophy of the plant. It is therefore discernible that **utilizing as much of the existing automation framework and the programs of the plant could lead to a quicker and economically viable approach to implement digitalization** to existing process plants. IntelliFlux benefited tremendously by adopting this approach for the process industry – particularly when it came to delivering an embodiment of decision automation to these plants without disrupting the current operation.

In both plants shown in Figure 2, the automation level could be enhanced considerably using digitalization, whereby several manual operations could be automated based on sensor feed and implementation of feedback and cascaded control loops. In both plants, IntelliFlux had to either suggest better placement of existing sensors, or addition of suitable sensors to improve the monitoring capability and process optimization using digital twins. The digital transformation strategy had to include sensor maintenance, and sensor fidelity assessment, which provided notifications to the operators to re-calibrate or clean sensors when they displayed any drift. Finally, utilizing internet, the plants were connected with the corporate management and process engineering teams through web-based dashboards and reports. In both plants, IntelliFlux implemented automated generation of reports for all stakeholders to provide daily, weekly, and monthly performance updates.

Delivering Digitalization by Closing the PDP Loop

Three aspects of Industry 4.0, namely, interoperability through IoT, transparency, and some elements of decision support can be implemented through partial actualization of the PDP loop, where the physical plant information is transported to a digital realm. This one-sided transport of plant data to the digital space and subsequent processing the data using appropriate computational infrastructure are quite straightforward and cost effective. These components of digitalization simply involve collecting all the input sensor data from the most readily accessible gathering points at the plant (typically the SCADA historian), and channeling these to a suitable database and computational platform for further processing and analysis, or displaying on web based dashboards or reports.

For many automation architectures encountered by IntelliFlux, this one directional data transfer can be achieved seamlessly, and in many cases, IntelliFlux offers these elements in its products at no cost (other than hosting data servers and customizing dashboards, or providing operator assistance services). This is also perceived as a lower risk implementation from a cyber security point of view, as any security breach of the system does not adversely affect the plant operations.

The upgrade to web based remote visibility of plant performance is often seen by plant operators as a major step change. They are extensions of the SCADA system, but are more versatile. Toolkits are also available to track the actual plant performance in comparison to the model predictions (from digital twins), forecasting based on historical data, and scheduling maintenance or component replacement. Availability of these information on the web can allow process management teams to meet remotely over video conferencing allowing them to compare and discuss results and plant performance from identical dashboards and reference information.

In the process industry, most businesses offering digitalization software or services are limited to this partial implementation of the digitalization strategy. The resulting implementations have ranged from simple remote monitoring systems, advanced monitoring and predictive maintenance services, various flavors of decision support and operator assistance services, and even platforms offering machine learning using acquired plant data as training datasets utilizing some form of artificial neural network (ANN) algorithm. The outputs of these information are typically provided to engineers, consultants, plant managers, and operators. The immediate benefit of this component is the ability of all stakeholders to look at the operational data and dashboards simultaneously, both on-site and remote. This cuts down on the human intervention and response time lag when problems arise at a plant. Furthermore, it is becoming increasingly attractive to attach such digital process and operations management platforms to the business operations management tools, such as schedulers, supply chain and project management tools, and enterprise resource planning (ERP) platforms to provide the connectivity between production and business management in a real time manner.

While these are exciting aspects of digitalization, and there could be serious value gains in such integrated systems from a business operations perspective, we have often encountered industrial customers who already had some form of integration achieved between their plant and business operations through their existing

SCADA frameworks. Paradigms such as just in time (JIT) or lean manufacturing were born out of such technologies several decades ago in some manufacturing sectors. Barring lower costs of deployment of such services, the real impacts of interoperability, transparency, and decision support through a one sided physical to digital domain data dissemination are often incremental and may not be immediately apparent to many end users who already have a SCADA system built in their plants.

Closing the PDP loop by taking the processed information back from the digital domain to the physical plant is a more complex task. This makes implementation of plant operations and performance optimization aspects of decision support and decision automation considerably more involved. This is where one needs to consider the logistics of delivering the digital information through multiple firewalls, communication protocols, and eventually reach the plant process control layer. The Programmable Logic Controller (PLC) is the only gateway of converting these high-level digital instructions into instructions that will manipulate the process level actuators of the plant to perform any task or cause a physical change in the process. This necessitates, among other things, a clear understanding of the core automation layer of the plant, and their embedded codes that control a process.

Some variation exists in the philosophy of how such digital to physical transformation should be implemented. One school of thought stems from proponents of edge computing. In this paradigm, an edge controller (conventional computing device which is more powerful compared to PLCs) is installed at the plant. The edge controller can communicate the higher-level information received from the digital realm to the PLC to change some of its programmed setpoints, without completely bypassing the existing operational logic already embedded in the PLC. This approach is somewhat similar to establishing communication between a conventional SCADA system and the PLC and could be considered as less disruptive to an existing plant.

Alternatively, there are ideas of completely replacing the PLCs and the original operational logic coded in them with more flexible and powerful multithreaded programs using edge controllers to directly control the RTUs. This second approach, though technically viable, could be considered more disruptive and expensive to implement in an existing plant. In particular, this will require rewriting and implementing the full set of automation instructions to bypass the PLC.

Notwithstanding the implementation methodology used for decision automation, the true value of digitalization is realized when the entire PDP loop is closed. This provides an enhanced level of automation that allows the plant to dynamically adjust and optimize its operation based on the transient inputs it receives from sensors. The closing of the PDP loop leads to implementation of the optimization steps through actions that are autonomously applied at the properly intended times making the plant truly responsive and smart. This is what Industry 4.0 aspires to achieve.

The Value of Digitalization

The benefits of digitalization in a retrofit process plant upgrade scenario depend on the existing state of automation of the plant, the desired digitalization goals, and the cost of upgrading the plant to achieve the digitalization goal. The primary benefits of converting a process plant into a smart plant can be broadly categorized into **economic benefits, reliability and operational flexibility enhancement, and achieving organization wide sustainability and circular economy goals**. The customers of IntelliFlux, however, mostly adopt digitalization primarily as a means to achieve: (i) lower operating costs, (ii) increase process throughput or yield, (iii) enhance operation and monitoring framework for remote plant locations, and (iv) explore autonomous control as an approach to improve reliability. The last factor is embodied in requests such as “can you make our sea water reverse osmosis plant operate through algae blooms”, or “can you make our water treatment plants work through influent water quality fluctuations”, or “can you make the drying process adapt to the different feedstock qualities”.

Economic Benefits

Customers are generally drawn to digitalization for their plants owing to its promise of achieving savings in utilities, consumables, and waste handling costs – OpEx in general. While these savings are real, and IntelliFlux delivers these practically in every installation, one needs to clearly assess the economic ramifications of these primary savings. If energy costs $0.10 per kWh, a baseline process consumes 1000 kWh of energy every day, and intelliflux saves 20% of this energy, the savings value translates to $20 per day. Therefore, energy savings alone cannot swing the dial toward adoption of digitalization if it is predicated only on the cost of energy saved. Now, if this energy came from a coal fired power source, and the GHG intensity of that power can be factored in for a carbon credit, the energy savings may provide more value to the plant owner.

Similarly, savings in chemical usage, downtime, component replacement, or reduction of waste volumes all have finite economic consequences. However, each of these savings have different implications for different sectors of the process industry. For instance, the waste volume reduction may have a direct impact on a plant that incurs a heavy expense in disposing their hazardous waste to a waste management facility. All of these savings will cumulatively reflect a general enhancement of the process efficiency arising from digitalization.

Enhancement of product throughput without capital expansion might have an economic impact if the product has a high value. For instance, if a sea water reverse osmosis plant productivity (recovery) increases by 5% due to digitalization, and the plant was originally producing 10000 m^3/day of desalinated water at a price of $0.80 per cubic meter, then the additional yield fetches $400 per day. Although this is attractive, one must weigh this against whether this additional production matches demand.

While these economic benefits aggregate to large numbers for owners and operators of large plants or multiple plants, these are often marginal for smaller operations. Thus, one needs to carefully assess the drive toward digital transformation based solely on economic benefits arising from enhanced process efficiency and OpEx savings in a single small plant.

Reliable and Flexible Operations

Mapping the value of digitalization only to improved process efficiency, higher throughput, or margin enhancement has marginal payback when it is associated solely with production economics. However, the return on investment from digitalization can appear more attractive when the plant reliability and operations management are considered. For instance, a single avoidance of a process component failure through early anomaly detection and intervention can avoid a plant shutdown for repair and maintenance. In such situations, the benefits of digitalization are more immediate. With IntelliFlux, a customer could avoid a ~3% annual revenue loss for the plant by preventing a single catastrophic failure incident.

How digitalization can affect plant maintenance and operations management labor requirement in the process industry is a contentious topic. Automation invariably takes a toll on the number of persons required to manage an industrial production system, and this has been perceived from the earliest phases of industrialization. Use of cranes to unload ships displaced manual labor at ports, and introduction of robotics in the automotive industry displaced a large segment of the automotive workforce.

However, for process industries, digitalization will probably not have as catastrophic an effect on the plant maintenance and operations management workforce as some envision. In fact, digitalization in many process industry sectors can possibly improve the quality of life of many who are currently forced to remain on plant sites, sometimes in hazardous environments, owing to the current state of automation at these plants. Better process guidance, timely alarms, automatically updated maintenance schedules, and visibility of plant operating status through remote computers, mobile devices, and PDAs can allow the professionals managing plant operations to deploy technical personnel to the plant sites on an as-needed basis. This cuts the exposure of personnel to hazardous environments and allows organizations to deploy human intervention to multiple remote plant sites from a centralized location.

With the COVID-19 outbreak in 2020, a couple of plants where IntelliFlux was installed needed to be operated and monitored remotely. With IntelliFlux, the operations teams were able to keep the plants operational while they were home quarantined, deploying only the necessary workforce as needed for in-plant tasks. These tasks included maintenance, filling chemicals, cleaning, and inventory management. The operations team adopted a remote working regimen where they communicated with each other utilizing the IntelliFlux dashboards, remote monitoring tools, and reports to assess the plant conditions and plan for any contingent actions. For nearly three months, the plant was operated with typically less than 25% of the operations team being present on the plant premises at a given time, while the teams met regularly through video conferencing augmented with sharing of historical and real-time plant information.

The knowledge sharing that was facilitated in this remote working setting was remarkable. Prior to the COVID-19 situation, some operators working on different shifts at the same plant never communicated with each other. Through the video conferencing between the operations team, where everyone shared the same plant data, the operations team was able to develop an unprecedented insight about the process. The knowledgebase components of IntelliFlux that aggregated the operator experience were enriched dramatically during these meetings. The learning components and databases used for the AI based analytics offered by IntelliFlux at these plants improved significantly through these inputs. Such a transition was deemed by the management as a radical potential benefit of digitalization.

Retention of highly experienced operators and process management personnel is a problem faced by the process industry in many markets. Process disruptions can stem from frequent operator replacement and variations in operator experience. Sometimes operation of some ancillary processes are outsourced to sub-contractors, and no knowledge of how these components are operated are retained systematically by the plant owner. Lack of, or partial visibility of, operational procedures are common pain points in many process industries. This causes gaps in operational knowledge, ability to project and control the costs, and even disruptions and knowledge gaps when operations teams need to be replaced. Digitalization can act as an insurance against such knowledge gaps. Digitalization and associated ability to retain context based operational knowledge of the process can ensure continuity and reliability when such disruptions of operations teams are encountered.

Sustainability and Circular Economy

The sustainability of process industries depends on gradually shifting from the once-through processing paradigms, toward the ability of processing multiple and negative cost feedstock, adopting just in time and on-demand manufacturing, minimizing energy and water consumption, and reducing/recycling waste. Extension of plant life and reducing life cycle cost of the product are also important aspects of sustainable operations. These concepts all depend on the smartness and adaptability of the process plants, such that these plants can accept feedstocks of variable quality and quantity, can turn up or down production in tune with market demands, and can intelligently utilize resources. Digitalization certainly has a role to play as an enabler of such sustainability drives.

Currently, when we speak to sustainability heads of large organizations, we see a lack of clear consensus about what sustainability and circular economy mean to the various segments of the process industry. One aspect of the problem stems from the rigidity of the production systems in which investments have already been made. The other aspect is that there are often no clear measurable metrics of showing economic gains through sustainability practices for the business in quarterly or annual reports.

Intelliflux has enabled several of our customers to define and measure sustainability focused KPIs. However, such sustainability metrics lack support and appreciation from certain segments of the stakeholders in the industry. For instance, at a plant of one of our customers, we achieved a reduction of wastewater volume by 43%. While the customer’s sustainability group found this number encouraging, there was no excitement in the production department, as there was no “real value” in reducing this water usage. This is because there was no cost of sewer disposal of this wastewater and the cost of intake water was negligible. In one of the plants in the food & beverage sector, we improved the life of filter modules beyond the currently mandated replacement time of 5 years. However, the customer had to follow regulatory mandates and replace these in perfectly good condition after five years. Filter cartridges or modules are usually disposed off to landfills or incinerated at the end of their useful life. If the reliability of these filter modules were assuredly extended beyond five years, discarding them following a regulatory policy adversely influences the sustainability goals of the business and costs money.

Reducing waste volumes was, however, of interest to our on-shore oil and gas sector customers who had to incur hauling and disposal costs to the extent of $0.60 - $1.20 per barrel (1 barrel = 0.159 m^3). In this case, there was a clear economic incentive to reduce waste volumes. We are also increasingly observing trends across the global sea water desalination sector to reduce their brine disposal volumes. Similarly, in many process industry segments, the concept of zero liquid discharge (ZLD) is gaining traction.

It was already shown earlier that reducing energy consumption has limited economic incentives because cost of energy is not significant. With respect to sustainability initiatives in large organizations, we often find conflicts between global sustainability drives vs. plant or operations-based sustainability drives when such initiatives are evaluated on an economic basis. A common example is the case of offsetting or reducing GHG and carbon footprint. Many businesses lean toward meeting sustainability goals of planting trees and investing in renewable energy to offset carbon or GHG footprint instead of focusing on reducing direct energy consumption or adopt lean manufacturing in their core operations. With respect to water management, we have encountered instances where zero liquid discharge with exponentially high energy costs receives greater priority over better water reuse strategies that conserve energy and reduce GHG emissions. These trends are signs that sustainability metrics are still at an early stage of development, with little progress made in quantitatively tying sustainability with stakeholder benefits in the process industry. We hope that greater process visibility at corporate levels through digitalization will allow these large organizations to achieve better parity between their resource intensities.

There are considerable benefits in retrofit digitalization as a sustainability goal for process plants, since it increases the longevity of existing plants, and makes production more efficient. Most process technologies are quite mature, and significant step changes in process efficiency cannot be expected from new technologies. Consider water treatment, for example. Biological treatment processes are probably some of the least expensive approaches for treatment and reuse of municipal and industrial wastewater. Membrane processes are also quite mature. These technologies work perfectly well when they are applied as intended. The process management and poor automation of the plants incorporating these technologies are often the key reason why they do not perform as advertised. Most recent improvements in reverse osmosis technology are primarily automation layer improvements. Considering this, extending the life of a plant, while making them smarter and more efficient through digitalization is perhaps the most judicious sustainability move for the process industry.

Summary of Benefits

Figure 3 shows an approximate breakdown of the overall benefits that we anticipate from a properly implemented retrofit digitalization of process plants. IntelliFlux Controls assessed and aggregated these benefits of digitalization to the process industry through its commercial experience. Not all the benefits are immediately attainable in all installations.

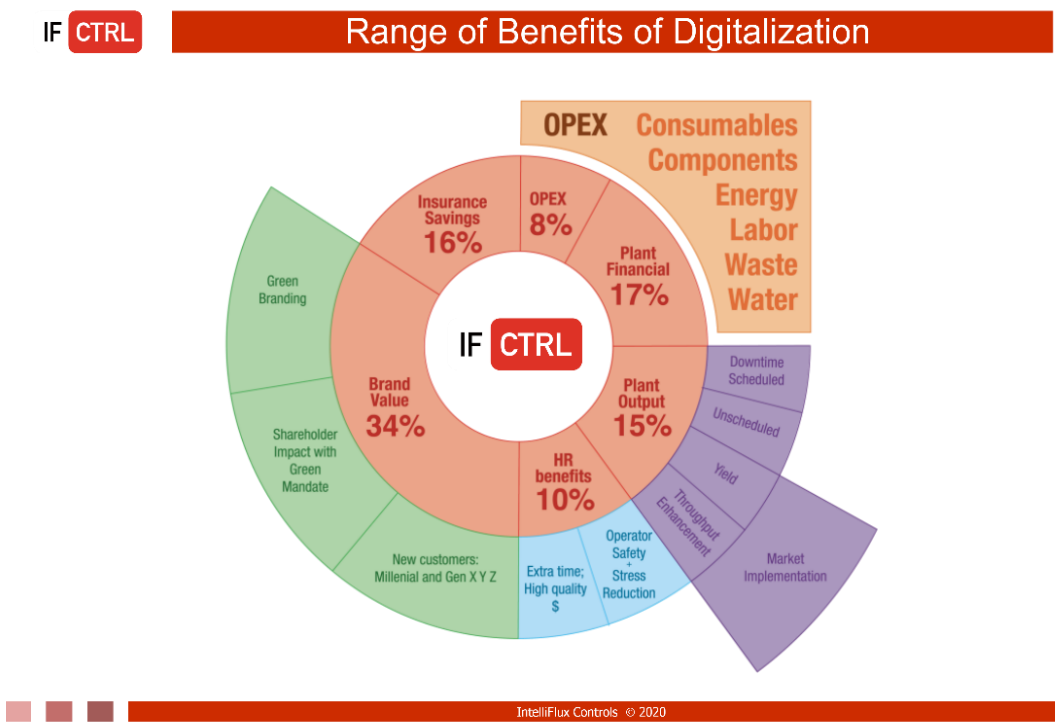


Figure 3: Summary of benefits from digital transformation.

About 25% of the benefits can be considered direct economic, stemming from OpEx and operations management savings. Reduction in plant downtime, increase in production throughput and plant yield are also beneficial if market implementation of the enhanced productivity and capacity is in place. This adds another 15% to the economic benefits. The benefits to the plant human resources is estimated at 10%. This comes from ensuring safety and stress reduction of plant staff and enabling operators to better manage the plant from remote locations. A large benefit (about 34%) can be associated with sustainability if the process efficiency improvements could be tied to suitable metrics that can be monetized. We particularly feel that companies in product spaces that primarily address new generation consumers can create tremendous brand value through adoption of resource savings, improved reuse and recycle, and lowering water, energy, and GHG footprint. Digitalization can provide an inexpensive pathway toward attaining these metrics without requiring complete overhaul of the existing manufacturing framework in the process industry. At the corporate management and shareholder level there is a strong appreciation of the sustainability related value proposition of digitalization. However, as one progressively moves deeper into the organizations with production and plant operations teams, the sustainability related values appear less important, the entire focus shifting to margin enhancement.

Finally, reliability enhancement afforded by digitalization can play a key role in risk management. Using digitalization, one can improve real-time visibility of the plant operations to a level that it can lead to significant adjustment in the actuarial values related to risk assessment. Better visibility leads to improved prevention of downtime, or catastrophic incidents leading to loss. Such improved visibility and ability to avoid loss engendered by digitalization can reduce insurance costs for the process industry.

Concluding Remarks

There are considerable benefits in retrofit digitalization for existing process plants, since it increases the longevity of these plants, and makes production more efficient without significant capital burden and disruption in operation. It is certainly one of the options that plant owners should keep in mind when exploring debottlenecking, capacity enhancement, or facility upgrades.

Most process technologies are quite mature, and significant step changes in process efficiency cannot be expected from incorporating new technologies. These technologies work perfectly well when they are implemented as intended by their designers and developers. Improper integration of these technologies and arcane automation of the plants coupled with lack of timely operator guidance are often the key reasons why these technologies do not always perform as advertised. Converting these plants to "Smart Plants" by superimposing a digitalization layer on top of the existing process automation layer through addition of primarily software modifications can add tremendous value to the process industry with minimal disruption. Considering this, extending the life of a plant, while making them smarter and more efficient through digitalization is perhaps a judicious sustainability move for the process industry.

Digitalization will not radically change your existing process plant, but implementing it in the existing plant can provide significant insight into the production process, which can transform the process of designing, building and integrating the next generation process plants. With digitalization, the currently operating plants can provide the training datasets to build and operate better and more sustainable process plants of the future. There are tremendous values to be gained from the data collected from today's plants, if we can unleash a higher level of computer aided learning to analyze and process the data.

Abbreviations

DCS	Distributed Control System
IP	Internet Protocol
ISMS	Information Security Management System
KPI	Key Performance Indicator
MCC	Master Control Center
MIMO	Multiple Input Multiple Output
OPC	Open Personal Computer
PDP	Physical to Digital to Physical
P&ID	Process and Instrumentation Diagram
PLC	Programmable Logic Controller
SCADA	Supervisory Control and Data Acquisition
TCP	Transmission Control Protocol
ZLD	Zero liquid discharge

Reference

1. Lasi, H., Fettke, P., Kemper, H., Feld T, Hoffmann, M., Industry 4.0. *Bus. Inf. Syst. Eng.,* **6,** 239–242 (2014).

2. Li Da Xu, Eric L. Xu, Ling Li, Industry 4.0: state of the art and future trends, *Int. J. Production Res.*, **56**:8, 2941-2962, (2018).

3. Tay, S. Te Chuan, L., Aziati, A. A., Ahmad Nur A. An Overview of Industry 4.0: Definition, Components, and Government Initiatives. *J. Adv. Res. Dynamical Control Syst*., **10**. 14**,** (2018).

4. ISO/IEC 27001:2013, Information technology — Security techniques — Information security management systems — Requirements, (2019).

5. ISO/IEC 27002:2013, Information technology — Security techniques — Code of practice for information security controls, (2019).

6. Keith A. Stouffer, Victoria Y. Pillitteri, Suzanne Lightman, Marshall Abrams, Adam Hahn, Guide to Industrial Control Systems (ICS) Security, Special Publication (NIST SP) - 800-82 Rev 2, National Institute of Standards and Technology (2015).

APPENDIX 1: Sample Digitalization Readiness Assessment

Industrie 4.0 Decision Automation Adaptability Score of Plant		
Basic Process Control Infrastrucutre		
Are system components controlled using PLC?	YES	1
Is full system controlled using PLC and HMI from an MCC? (Master - Slave Configuration)	YES	1
Is a plantwide SCADA system available?	YES	1
Is wireless communication available?	YES	1
Is Ethernet/LAN connection available?	YES	1
Is internet access possible?	NO	0
Are setpoints adjusted though HMI of PLC, MCC, or Control Room?	HMI at MCC	0
Are Pumps operated using VFDs?	YES	1
Is SCADA Historian available?	YES	1
Are all RTUs/Field Instruments Connected to Master PLC?	YES	1
RTU Automation Level		
Are Level measurement instrumentation tags available for all tanks?	YES	1
Are Flow measurement instrumentation tags available for main flow points?	YES	1
Are Pressure measurement instrumentation tags available for key state points?	YES	1
Are Temperature measurement instrumentation tags available for key state points?	YES	1
Are any Water Quality Monitoring instrumentation tags available?	YES	1
Is plant normal operation fully automated?	YES	1
Is plant startup sequence fully automated?	NO	0
Is plant shutdown sequence fully automated?	NO	0
Is individual unit process / operation cleaning automated?	YES	1
Is CIP automated?	NO	0
Is dosing of chemicals automated?	YES	1
Is chemical dosing tunable (for e.g., adjusted with influent water quality)?	YES	1
Industrie 4.0/IIoT Readiness		
Are PLC Systems built after 2010?	YES	1
Is SCADA system built after 2010?	YES	1
Is MODBUS supported?	NO	0
Is OPC supported?	NO	0
Is TCP/IP supported?	YES	1
Is MQTT supported?	NO	0
Has any IoT device been installed?	NO	0
Do operators use proximity based wireless communications?	NO	0
Is SCADA system connected to Internet?	NO	0
Does SCADA system contain CyberSecurity Measures?	NO	0
Is Air Gap policy used at Plant?	NO	0
Are mobile/wireless devices used in plant?	NO	0
Are GSM/Cellular devices used in plant?	NO	0
InterConnectivity Readiness		
Are there multiple unit operations and processes in the plant?	NO	0
Are the unit operations and process operations integrated at MCC level?	NO	0
Are individual unit operations/processes operated through their individual PLC programs?	NO	0
Do multiple unit operations and processes have automated interrelated operation sequences?	NO	0
Is process integration programming performed on the Master PLC (on MCC)?	YES	1
Is process integration programming performed at the SCADA level?	NO	0
Is SCADA system able to control individual process setpoints?	NO	0
Is SCADA system able to optimize any process performance automatically?	NO	0
Is system automation designed to respond to influent water flow rate and quality variations?	NO	0
Is system automation designed to respond to temperature variations?	NO	0
Decision Support		
Is SCADA historian monitored?	NO	0
Is SCADA historian used to provide reports to operator/management?	NO	0
Is SCADA system connected to any MES/ERP system (e.g. ordering chemicals?)?	NO	0
Are alarms delivered to any recipient beyond MCC or Control Room?	NO	0
Are status reports generated by system automatically?	NO	0
Is SCADA system able to deliver email/SMS/pager or similar notifications of alarms/exceptions?	NO	0
Do operators access HMI dashboard outside of plant floor or control room?	NO	0
Are weekly, monthly, or quarterly reporting automated?	NO	0
Are any plant parameters (e.g. membrane replacement, chemical depletion, etc.) predicted?	NO	0
Are there any advance warning / predictive analytics feautres present in the SCADA?	NO	0
Decision Automation		
Can plant operate in normal operation mode without human operator assistance?	NO	0
Can plant shutdown without operator assistance?	NO	0
Can plant startup automatically without operator intervention?	NO	0
Can CIP and maintenance functions of plant be conducted without operator intervention?	NO	0
Are plant components (e.g. UF system) desigend to detect performance drifts and change?	NO	0
Can plant transition between different states (operation, shutdown, startup) without human intervention?	NO	0
Score	**21**	
Assessment:		
Level 2: Basic PLC automation. SCADA level upgrades needed.		

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