DIGITAL TRANSFORMATION AND EXPANDING CAPABILITIES OF INDUSTRIAL PROCESS CONTROL AND OPTIMIZATION

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Abstract

Recent advances in developing new capabilities for industrial control systems and applications reveal opportunities to address well-known challenges and accelerate the adoption of new technologies in the process industries. Examples include a) Open Process Automation (OPA), which provides the framework for increased integration and interoperability of process control systems and b) the integration of IT technologies into the process control domain, which accelerates applications development and deployment across the process control network. The increasing penetration of Artificial Intelligence/Machine Learning (AI/ML) in the process control area is enabling the progression to more autonomous operation and accelerating the deployment of hybrid modeling for online operations. The penetration of control and optimization applications is also increasing as we further expand into the upstream domain and our newest business, low carbon solutions. These new directions also present new challenges as well as opportunities for advances in technology through increased collaboration between academia, vendors and industry.

Keywords

Autonomous Operations, IT/OT convergence, Hybrid Modeling, Low Carbon Solutions

Introduction

The current industrial process control & optimization paradigm (Figure 1) involves multiple technologies with different objectives, scopes and timescales. Starting from the bottom of Figure 1, the Distributed Control System (DCS) layer is providing the basic and advanced regulatory control functionalities to the field at a high frequency rate (e.g. PID controller). The advanced process control (APC) layer includes dynamic multivariable control technologies which provide the set points to the DCS layer. The main objective of this layer is to coordinate the PID controllers to transition the operation to its constraints. The steady state Real-Time Optimization (RTO) layer is providing the economic optimum to the APC layer and assists the controls to switch to an operating point where all variables are not residing at their constraints. The remaining two layers at the top interact with RTO and provide the necessary limits and prices to the online optimization application in order to calculate the economic optimum.

Additionally there are other classes of applications which are an integral component for successful plant operation. Examples include applications with focus on a) accurate monitoring of units, b) early detection and diagnose of failures, c) operator training simulators (OTS) and d) automation of transient operations and sequential control.

Application development is performed using a combination of IT infrastructure available across multiple domains and equipment available on process control networks. Online technologies (e.g. DCS, OTS, APC, and RTO layers) are deployed through the process control network while offline technologies (e.g. Scheduling and Planning) use the Enterprise network. Moving forward, we are seeing changes in the area of application development enabled by better use of widely used IT infrastructure and technologies. Requirements for a high degree of network security and cyber-security considerations are also playing a key role in defining current and future infrastructure.

Although all layers of the industrial process control & optimization scheme interact with each other, they still have different control/optimization objectives and underlying mathematical models in each layer which may result in conflicts during the coordination and potential sub-optimal operation. Progress was made on the alignment between MPC/RTO layers (Peterson et al. 2013) however we believe that the alignment and integration of different layers in Figure 1 is still an open problem.

The success of an industrial process control & optimization scheme requires all layers and technologies to be aligned and provide solutions that can be explained to the site engineer. The accurate interpretation and explanation of control and optimization solutions requires toolkits which utilize a large number of data generated by the process control applications. Systems infrastructure, data processing and visualization of large data sets are key enablers for this task. These types of solutions analysis tools have been deployed for online optimization applications in ExxonMobil (Cozad et al., 2019) and have contributed significantly to the success of closed-loop implementations.

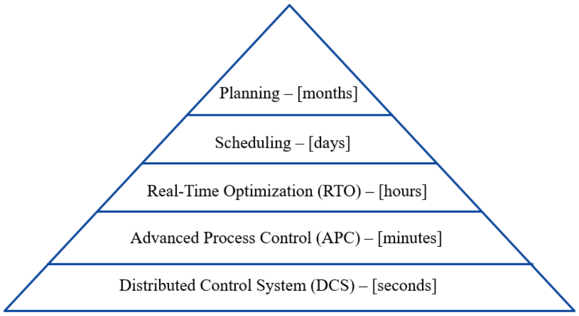


Figure 1. Industrial Process Control & Optimization Scheme

The industrial experience of deploying and sustaining process control & optimization applications revealed opportunities to accelerate capability development for various technologies through innovation and enhanced collaboration between academia, vendors and industrial partners. In many cases the vendor proprietary nature of current generation of distributed control systems limits the flexibility to take advantage of advances in computing technologies as well as new applications technologies such as those used by the data science and other communities. Moving towards a more open system architecture can benefit the process industries significantly, which was part of the initial idea of the Open Process Automation Forum (OPAF). The OPAF was formed in 2016 and it has more than 100 members including vendors, suppliers and end users.

Open Process Automation (OPA) is a reevaluation of the industrial automation industry with the goal of replacing vendor proprietary systems with a standards-based, secure, and interoperable architecture for process control. A schematic depiction of OPA architecture is shown in Figure 2. ExxonMobil has been a pioneer in this area and has progressed this concept from ideation to an industry wide initiative, and is now moving to put the principles in action with a field trial using commercial devices built to the emerging standard.

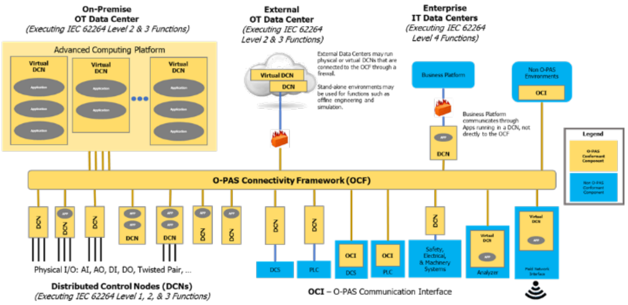


Figure 2. OPA Architecture

One of the key enablers of OPA is the use of containerization, which is the next generation of virtualization technologies. This enables the software from different vendors to be deployed to the same device interchangeably, from the smallest edge device to the server class machines.

The use of containerization is not limited to ExxonMobil's efforts in OPA, but incorporating a container deployment environment within the traditional process control environment is also actively being pursued. This environment will not only enable the development of custom applications that can take advantage of micro service type software architecture but ultimately be a method of directly deploying versions of vendor software more efficiently.

Evolving use of computing infrastructure in automation and contol

The concept of an Advanced Compute Platform (ACP) is identified as a key enabler for OPA. This platform is based on standardized technologies available today, but more widely used in other more IT focused industries. The ACP includes containerization and orchestration capabilities as well as many infrastructure items giving it very high availability. These concepts and capabilities are something that ExxonMobil has an interest in bringing to all of its manufacturing facilities even before OPA becomes more widely available. New capabilities that are of interest are the ability to develop applications that are broadly applicable to multiple sites (analogous to the App Store), where only straightforward configuration needs to be done during deployment specific to that installation. We would also like to utilize modern software development and sustainment techniques. We are interested in making it easier for applications to utilize data from a variety of sources, beyond time series process data and potentially including securely connecting to vendor cloud resources. Over time we hope to have an ecosystem where we leverage expertise of a central group, engineers resident at specific sites, as well as external parties (vendors, academic partners).

In our current process control systems there is very clear delineation between the process control and enterprise networks for cybersecurity reasons so the full capabilities would be distributed. This includes a high powered multi-user environment at the enterprise level including code management and a pipeline process to prepare payloads for deployment, and a leaner container deployment platform within the process control domain.

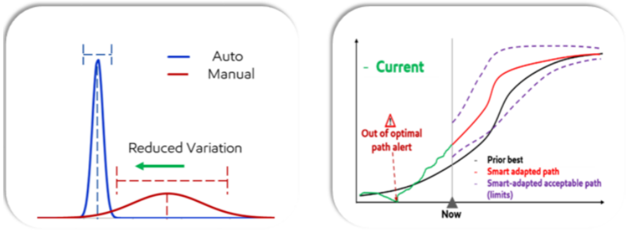
One significant focus of these efforts is also on how we re-architect process control applications from large monolithic pieces of code managing all aspects of operation (communication with I/O systems, data pre-processing, algorithm processing, etc.) and move to developing robust, reusable elements, in more of a micro services structure. What may be a traditional application now would be built up from multiple elements deployed as individual containers. The interface becomes the important element, not the code internal to the application providing a service. Python is the language of choice now, but as programming continues to evolve, the code in any one container can be rewritten with no disruption as long as the interface remains constant.

A platform that enables more direct deployment of containers also positions ExxonMobil to be more agile in how it interacts with universities and vendors. In the past collaborating with academia was challenging and required adoption of many more cutting edge tools, which can be time consuming at best in a research environment, and very difficult in a production environment. Having applications or code available in a containerized form could enhance collaboration and enable more concepts to be proven out with industrial data. Additionally when vendor applications are available in this form it would reduce our testing time allowing us to take advantage of the features in new releases more quickly.

Autonomous operations - leveraging AI/ ML/ modern compute capabilities

~~Like many in the industry,~~ ExxonMobil is leading manufacturing operations digital transformation through its Intelligent, Self-Optimizing Plant program. The key objective is to simplify operators & engineers decision-making and to deliver a step-change improvement in their effectiveness. The operator is still necessary for smooth operations, particularly during transient operation or when abnormal events occur. Operators need to synthesize large quantities of data and manipulate potentially hundreds of variables to react to an event or improve operations. One active area is to augment them with support tools that can improve the effectiveness o~~r~~f operations without increased workload and complexity. An example of applications of this type is included in Figure 3.

The maturity of AI is more modest than its potential, but we're starting to see how it can be part of an improvement loop including sensing, benchmarking, contextualizing, and turning that information into action. At manufacturing sites control capability has continued to evolve (Figure 4), from basic controls, to advanced regulatory controls, then multivariable control and model predictive control to real time optimization using engineering principle based models. When alarm and operator advisory systems are included this constitutes a sophisticated system suitable for the largest and most complex industrial processes.



iPerform - autonomous control/optimization (Deployed at scale)

SmartLane Transient Operations Advisor (Deploying)

Figure 3. Developing Autonomous Technologies to Empower Operators and Engineers

The next step in this progression is to move toward highly autonomous operations, further helping an operator supervise the operation without increased workload. This next phase is really about smart integration of automation technologies with cognitive and orchestration capabilities to recognize common situations and take the required action or to provide just in time insight where an operator decision may be required. We hope to bring these types of support capabilities, enabled by a combination of engineering principles, artificial intelligence and machine learning, to our manufacturing facilities to reduce the cognitive burden on operators and allow them to consistently deliver improved operations under all circumstances.

ExxonMobil is currently working to determine where the opportunities are and cut through some of the hype to determine what can be implemented now. This approach to innovation is intended to be agile: start small, experiment quickly, and identify barriers to scale up. Indeed, we have early wins (Kadam,2022) through development of operations support technologies, to name a few ~~are~~(Figure 3): a) early stage operator virtual assistant, b) cognitive computer vision for autonomous monitoring & control, c) operator guidance for transient operations, and d) autonomous control and optimization of highly nonlinear operation.

Acknowledging the opportunity of external leveraging, ExxonMobil is evaluating defining an open challenge problem for autonomous operation. This area needs the most partnering with academia and vendors. Early considerations for academia for helping the industry are, by keeping the application in mind, determine which technologies are suitable for industrial application, and what improvements they offer above existing control technologies. In the area of advancing autonomy, there is a need for advancement in the use of networked agents of smart applications-systems-sensors, and their orchestration / adaption / augmentation with cognitive native language programing and traditional automation. In the area of smart sensor , the need is for advancement in wireless edge smart & physical / soft sensors & control valves. Further, algorithmic developments are needed for intelligent detection of operation modes, data contextualization, and emerging cognitive vision model based optimization.

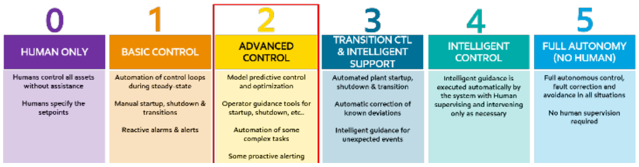


Figure 4. Autonomous Operations Levels — Integration of Artificial Intelligence with Automation

We would be looking to vendors to increase the speed of delivering products to the market with features that enable easier integration into process control environments. This includes making applications available in a containerized form so less engineering is required for deployment. If applications are best deployed with integration to cloud based resources, they must be designed with security in mind so they can be securely interfaced to process control systems. We also need vendors who are interested in moving beyond the traditional control applications and moving into the space of information synthesis and decision support enabled by ExxonMobil's modern compute and cloud compute capabilities. This may involve self-learning and organizing applications.

Increasing capability of optimization technology

The traditional RTO technology relies on detailed physics-based mathematical models with a scope ranging from a unit to an entire plant. Those models are deployed online for closed-loop steady-state optimization where real-time plant data are used to a) update the structure of the model (e.g. unit status on/off), b) reconcile the model parameters in order to match the current plant operating state, c) update the controller settings and process limits within the RTO model, d) calculate the optimal operating conditions and e) send the new operating conditions to the advanced control system for implementation. A schematic description of a typical RTO sequence is shown in Figure 5.

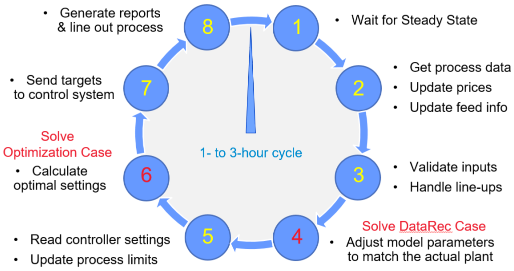


Figure 5. Example of an RTO sequence

Traditionally physics-based models have been used in refining & chemicals space where the majority of the unit operations are well-understood and physics-based models have been developed for various conversion units (e.g. Fluid Catalytic Cracking, Naphtha Reforming, Steam Cracking etc.). An example of the scope of a traditional RTO application is shown in Figure 6 where physics-based models are being used to predict and optimize the steady-state behavior of the cracking furnaces, refrigeration systems and fractionation units.

The use of physics-based models provides an advantage with respect to understanding the optimization solution however their use is limited to areas where the physics are well-understood and physics-derived equations are available to represent the physical behavior. In addition to this, the use of those type of models results in large-scale models which can limit the scope of the application and hence limit the potential optimization handles. The latter was addressed with the development of integrated RTO technology (Andrei et al., 2011) which coordinates multiple distributed RTOs enabling a plant-wide optimization at the expense of increased complexity and higher application support requirements.

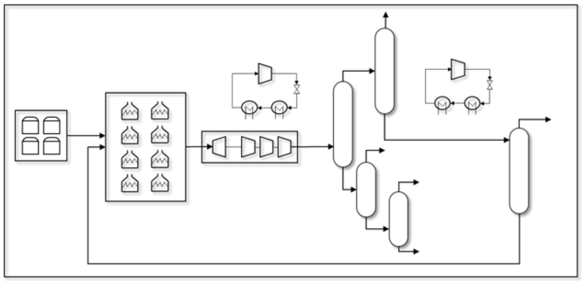


Figure 6. Scope of an Olefins RTO application

Employing hybrid models for online optimization has the potential to overcome current limitations of physics-based approaches and opportunity to expand online optimization technology in new areas. Incorporating key physical constraints (e.g. mass & energy balances) in hybrid models can improve solution validation and interpretation. Verifying directionality (e.g. gains) is another important element for successful online (closed-loop) deployment since it guarantees alignment and synergy between the optimization and control layers. A potential gain misalignment across the control and optimization domain can result in conflicting signals, loss of trust to the applications and limited use of the application from the operations personnel. The process industry will benefit by advances in imposing desired behavior during the data-driven/hybrid model development.

Applications with an inherent dynamic nature will be benefited by advances in hybrid modeling suitable for dynamic optimization. Computational performace is a key success criteria for a successful implementations of applications employing dynamic optimization. As the scope of those applications increases, the size of the underlying mathematical model grows making it the limiting factor for these type of applications. Accelerating the commercialization of advances in academia will enable the industry to increase the speed of deployment. Overall, a closer collaboration between academia, vendor and industry will be beneficial in developing, testing and commercializing new technologies.

Beyond large integrated manufacturing facilities

Expanding the penetration of process control technologies in new areas (e.g. Upstream operations) impose additional challenges. The life span of those assets is shorter compared to the traditional downstream and chemicals manufacturing facilities. In addition to this, these facilities are mainly remote in nature and require technologies to enable more unsupervised, more autonomous operations where active monitoring from operators may not be possible. Some of the challenges in deploying current technology in new areas are included below:

- Remote in nature with limited connectivity to locations where the process can be monitored or controlled.
- Changes requiring field operator must be infrequent
- Devices doing control are less powerful and integrated compared to traditional DCS
- Long distances between facilities managed by a single operator
- Equipment limitations regarding availability for continuous actuation

Despite the challenges, applications have been successfully deployed, however, those applications are typically smaller in scope. The same underlyingtechnology is still applicable, however the nature and the environment of the deployed application requires additional considerations for deployment and sustainment. Enabling fast deployment and limiting sustainment requirements can significantly improve the benefits over the lifecycle of applications in this area. As ExxonMobil is looking into the future and moving into the low carbon solutions area we expect to face similar challenges as in Upstream and other non-traditional environments.

Conclusions/Key messages

Digital manufacturing operations transformation is needed, ExxonMobil is on the journey of increased autonomy. We are developing autonomous technologies to empower operations support staff while validating AI hype versus reality through agile approach to innovation- start small, experiment quickly, scale fast. Our experience suggests that the success of autonomous technologies requires integration of first principles with AI/ ML instead of pure data driven AI approaches.

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