PRACTICAL APPLICATIONS OF A DYNAMIC DIGITAL TWIN

HONEYWELL FORGE

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ABSTRACT

Rigorous process simulation tools are extensively used in engineering projects. These tools support analysis and decision making through initial project phases of opportunity identification, preliminary design and detailed design.

Dynamic simulations are less frequently applied in engineering projects and, if used, are specified solely to support Operator Training Simulations (OTS) for process unit start-up. Although the benefits of deploying a dynamic Digital Twin simulation model for engineering projects are well documented, it is not widely practiced, primarily due to upfront costs, incompatibility of steady-state and dynamic simulation tools and the specialized skills set required. In this paper, we review the requirements, value and benefits of deploying a dynamic Digital Twin model for project analysis, decision making, design validation and operational readiness to support safe and effective commissioning and start-up as well as on-going applications for process performance management.

INTRODUCTION

> **The development of viable products and processes is often depicted and described as a series of phases ranging from the initial Opportunity Analysis through to Operate and Improve. Individual activities during each phase can be highly iterative and, in the early stages, a phase gate decision is made to either proceed, revert or abandon prior to progression to the next phase.**

There is no one standard process for the design and execution of major projects, but for the discussion herein, we will consider the project development process generally applied in process industries, which is illustrated in Figure 1.

Process simulation has been a key tool for process industries for decades. Historically, steady-state process simulation technology was utilized during the initial Opportunity Analysis and Selection phase to review varying process design and configuration options to select a favorable design basis. During the Preliminary Design and Detailed Design phases, steady-state models support engineering, selection and sizing of key process equipment.

Steady-state simulation results provide a snapshot of the starting and end conditions. It cannot provide a realistic and credible indication of the process behavior during transients. On the other hand, dynamic process simulation can predict stability, controllability and intermediate process conditions during transients such as start-up, shut-down, transitions and disturbances, all of which can influence important design conditions that improve process stability, safety and performance. However, inherent value aside, the widespread use and application of dynamic simulation within the project engineering discipline is still more of an exception than the rule.

The first applications of large-scale rigorous high-fidelity dynamic simulations have been fit-for-purpose simulators primarily focused on console operator start-up training. These dynamic models were based on unique proprietary software technology that were often incompatible with the steady-state simulation tools used

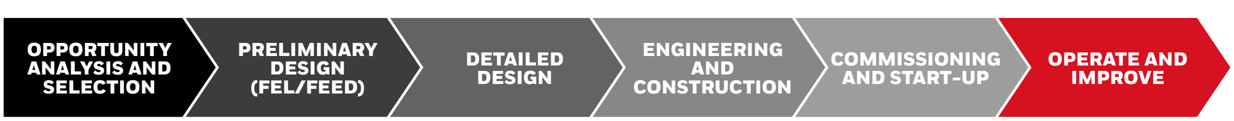


Figure 1: Engineering Project Phases

by the project design and engineering teams. The value of these customized training simulators was their replication of the detailed process control and safety system configurations and Human-Machine Interface (HMI). The integration of the training simulator dynamic model with the operating console, the process control system and safety systems provided a credible and realistic real-world replication and experience for console operator trainees analogous to a pilot's flight simulator.

The precise replication of the automation and safety system configuration proved extremely useful. It consistently exposed latent defects, opportunities for improvement and their corrective actions in the control and safety system performance. Dynamic simulation models were quickly recognized by the automation team as a valuable tool for control and safety system validation. As the fidelity and performance of operator training simulators improved, other project engineering disciplines also took notice, discovering the added value that rigorous high-fidelity dynamic simulation can deliver through new analysis, design and decision-making capabilities. Coincidentally, commercial simulation vendors recognized this value too, and dynamic simulation tools began the evolution towards a single platform, thermodynamics, solution engine and user interface to create a suite of simulation capabilities applicable throughout the lifecycle of the project.

With the unification of the simulation platform and the exposure of the dynamic simulation capabilities to a broader base of both users and consumers, the terms Life Cycle Simulator (LCS) and Multi-Purpose Dynamic Simulator (MPDS) were born. LCS recognizes the full spectrum of simulation capabilities, extending the steady-state design simulation to include dynamic simulation throughout the project, while MPDS was focused on the use of an evolving integrated dynamic process model throughout the design, development and operational phases of a project to improve the entire development and deliver a flawless start-up and commissioning outcome.

Shell's Pearl GTL project in Qatar was a pioneer in the application of MPDS, or dynamic Digital Twin, and formerly acknowledged a complete suite of realized benefits to deliver the following (1):

- Engineering studies during EPC Phase for detailed verification of engineering design
- Flawless Start-up Test of complex process control schemes, instrument safeguarding, and Operations (trip) scenarios
- Testing/verification of commissioning and start-up procedures using simulator
- Pre-design all aspects of plant operation including operation under advanced process control
- Periodic refresher training and testing
- Certifying operators for competence
- Project related HMI training
- APC development

As the flawless start-up and commissioning experiences and value become more widespread, many process industry companies, particularly those making large scale capital investments in greenfield sites, took notice and accepted the challenge of how to apply dynamic Digital Twin models within the engineering project as an evolving best practice. Herein, we will focus on the applications and benefits of the dynamic Digital Twin throughout the project and during the continuous improvement activities that are prevalent during the Operate and Improve phase.

THE DIGITAL TWIN

In the context of MPDS it is important to understand the term Digital Twin. Digital Twin terminology has been revitalized as part of recent Industrial Internet of Things (IIOT) trends. Modern Digital Twins are accurate digital replications of a physical objects or processes to provides new insights into behavior and performance.

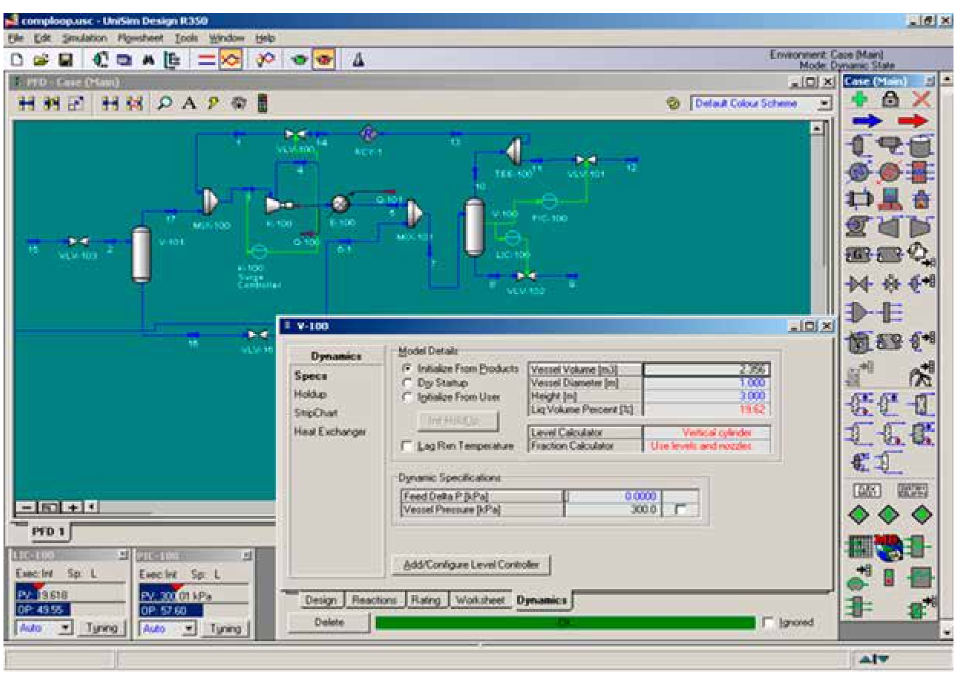
For engineering project applications, the Digital Twin begins as a future representation of the physical process, which enables insights, decisions and actions that will lead to the future state desired capabilities and performance. When the Digital Twin is synchronized with its real-world counterpart, it can provide a near real-time replication of current conditions, providing insights applicable to current conditions that may be otherwise unknown. Extending the application to the past, a Digital Twin that accurately reflects the state of an asset at a prior point in time can provide useful information to understand decisions and actions which led to the current state. MPDS, as a tool to provide new insights, is a Digital Twin application that, when used effectively, will improve overall asset behavior and performance.

RIGOROUS DIGITAL TWINS IN ENGINEERING DESIGN

During engineering design and execution, rigorous steady-State process simulation is a well proven tool, which is first used during Opportunity Analysis and Selection and then used heavily throughout subsequent phases as the simulation models are continually updated as engineering decisions are confirmed and engineering data is defined in more detail.

Comprehensive Digital Twin process models provide engineers with a complete view of heat and material balances for evaluating limiting design cases and other operating conditions. Additionally, simulation is used to perform feasibility studies, assess alternative process configurations and identify risks. Engineers leverage this information to ensure designs are safe, meet environmental regulations and maximize the operational and business performance of the asset.

A steady-state Digital Twin can only provide a snapshot of the starting and end conditions, while a dynamic model can accurately predict intermediate process conditions during the transition. With the capability to replicate start-up, shut-down, the impact of equipment failures, and other abnormal conditions, a dynamic Digital Twin can better serve engineering design analysis, decisions and outcomes that otherwise may not be known or will be discovered far too late in the project lifecycle.



The application of the dynamic Digital Twin can therefore support robust planning and design early in a project's lifecycle, at a time when the ability to influence changes in design is relatively high and the cost to make those changes is relatively low[2]. Early use of dynamic simulation tools is particularly valuable for highly capital-intensive, long lifecycle projects. Although it may add time and cost to the early stages of a project, the incremental investment is minor when compared to the costs and effort required to make changes during later stages or, in the worst case, during commissioning and start-up.

To best apply and deploy dynamic Digital Twins, it is important to select and deploy simulation tools that can best enable a common simulation platform for both steady-state and dynamic simulation applications throughout all phases of the engineering project. With the right simulation tools and end user experience, the application and deployment of process Digital Twin models are no longer limited to narrow use-cases but can now be extended to analysis, deployment and validation activities that unlock significant incremental value across the complete project life cycle.

Today, most of the broad-based applications of the dynamic Digital Twin in engineering projects continue to leverage a planned delivery of an OTS; however, compared to the past, the engineering and development of dynamic models begin much sooner in the project, and as early as the Preliminary Design phase. These same models evolve into the OTS deliverable and, as such, much of the model development contributes to high-fidelity, credible and realistic training simulation experiences that are so important for flawless start-up and commissioning.

There are many documented successes for the application of the MPDS or dynamic Digital Twin in an engineering project. In practice, the applications of the dynamic Digital Twin recur throughout the project phases as increasing level of information feeds higher fidelity and complexity to help refine and/or confirm the analysis and decisions that deliver cost savings, improve schedule and contribute to process safety, reliability and performance. In the following section, we will review typical applications, their outcomes and value created.

SIZING FLARE AND BLOWDOWN FACILITIES

Effective flaring and blowdown is required for safe plant operation. During process upsets, the safety relief system functionality is vital to prevent equipment damage, fires, explosions and injuries to personnel. The design of these facilities is centered on confidence. Confidence that the system can handle the maximum design flow suitable for the entire range of possible operations. Dynamic simulation enables the confident study of controlled blowdown procedures to avoid unnecessary flowrate peaks. The dynamic simulation models help improve the design of relief and blowdown systems through more precise calculations of relief loads and often a confident reduction in the flare loads can reduce the capital expenditure (CAPEX) for the flare and blowdown facilities while increased accuracy improves intrinsic safety[3].

PROCESS EQUIPMENT SIZING

Equipment sizing is an important consideration that impacts capital costs, controllability, turndown and unit performance. During early phase analysis, it is common to specify oversized equipment, particularly when exact process conditions, and potential transients are unknown.

As equipment size grew, so did the costs, and the need to specify the “right” sized equipment. During the development of large LNG trains, high-fidelity dynamic Digital Twins were introduced to study turbomachinery applications and to validate the size and performance of large LNG compressor train equipment. Many projects realized a significant reduction in CAPEX, by investigating process transients, controllability and stability to reduce "Opinion Engineering" of plant design, and provide "twenty-twenty hindsight before start-up" [4].

HAZARD AND OPERABILITY STUDIES

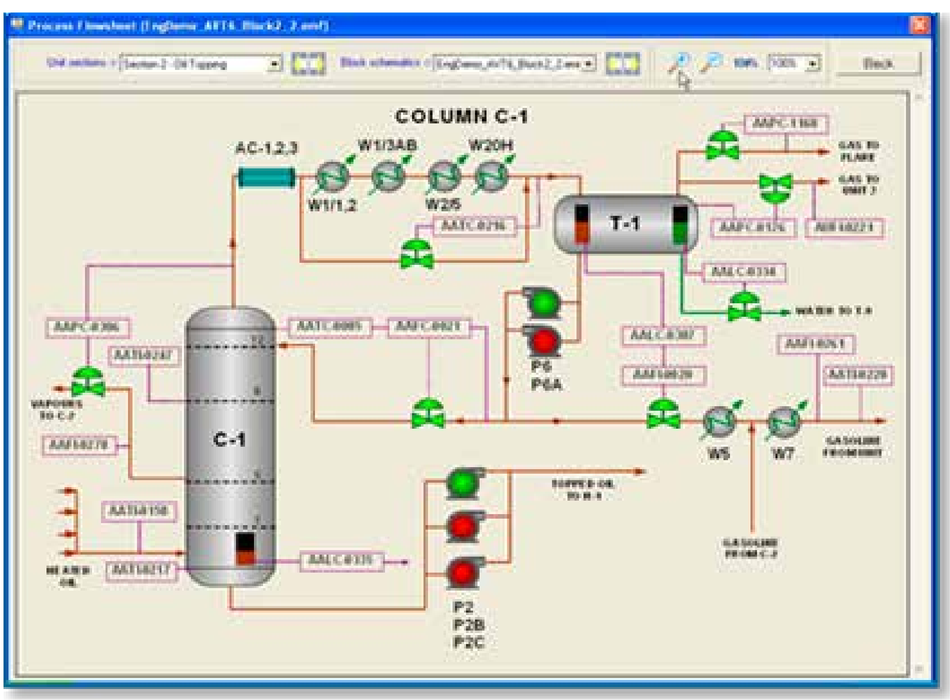
A hazard and operability study (HAZOP) is a systematic procedure for critical examination of the operability of a process. Whether applied during design or on an operating plant, it indicates potential hazards that may arise from deviations from the intended design conditions.

Typically, the standard HAZOP process is completed with Subject Matter Experts (SMEs) who hypothesize what can happen for each scenario of interest. Dynamic Digital Twins can enhance the HAZOP process by providing a better understanding of the transient responses and their consequences. Dynamic modelling can also establish threshold values that lead to a high-risk probability, examining and re-examining designs for safe range of operation and to select and test risk mitigation strategies. Dynamic simulation results improve the HAZOP process and operational safety by supplementing the SME discussion with a rigorous and credible engineering evaluation of the dynamic process response[5].

PROCESS STABILITY

Complex innovative process designs often have inherent instabilities that must be addressed during control and safety system deployment. Although instability can be managed well at design conditions through the application of specialized advanced control schemes, these same applications are impractical to apply to routine non-normal operating conditions such as start-up and shut-down.

A better approach is the use dynamic Digital Twins to understand and address process stability during design by influencing both the design decisions and the understanding of process control and safety system requirements. Improving process stability throughout a range of potential process conditions can greatly reduce operational risks and reduce quantity and severity of potential incidents, all while improving overall performance. [6, 7, 8, 9]



SAFETY SYSTEMS DESIGN

The validation and design of safety systems is a vital part in the commissioning of any new facility. Leading Health, Safety and Environmental (HS+E) performance are the goals of all reputable companies; however, since as-built safety systems are exercised so infrequently, it may take years to recognize, understand and address flawed designs.

A dynamic Digital Twin can provide realistic real-time process responses across a wide range of events to help scrutinize and dissect safety schemes. Using defined operating scenarios, the process can be repeatedly operated through various upsets such as: compressor surge, depressurization/flaring events and total plant shutdown. This allows for an iterative process wherein the proposed safety system is tested and improved to account for all possible outcomes. Furthermore, the proposed changes can be reviewed by the HAZOP team to further investigate the operational integrity[10].

PROCESS CONTROL AND SAFETY SYSTEM VALIDATION

Although early-phase design decisions facilitated by the application of the dynamic model will have a positive effect on automation and safety systems operability, the real work of process control and safety system engineering begins in earnest during the engineering and construction phase. During this phase, the process control strategies may pass simple loopback testing, but complex behavior and interactions are only experienced once the controls are connected to the process.

A dynamic Digital Twin can realistically exercise the control schemes and HMI to help identify and resolve latent issues and their corrective actions. Conveniently, at this stage the OTS dynamic Digital Twin application will also need to integrate the control and safety system into the end-user training simulator. This activity is often the first realistic testing and validation activity for the control and safety systems. Furthermore, OTS testing always includes a full start-up and shut-down, as well as other dynamic training scenarios, such as equipment failures, etc. The control and safety system therefore is exposed to rigorous testing scenarios that are closely aligned with the actual plant response, enabling identification and resolution of potential problems before they become expensive and time-consuming distractions during the start-up and commissioning phase. Furthermore, the tuning of controls within the OTS to ensure a safe and stable simulated start-up have proven to also be directly applicable as the initial controller tuning for start-up and commissioning. (1) .

MULTIVARIABLE PREDICTIVE CONTROLS

The design and development of Multivariable Predictive Controller (MPC) strategies are often left as an end-user responsibility to develop and deploy following start-up and commissioning.

Having MPC configured, tuned and available prior to start-up can incrementally drive immediate performance improvements. Prior to start-up, the dynamic Digital Twin is a best representation of the physical asset and can be successfully used to support the initial MPC design and deployment. Having MPC ready and available immediately following commissioning can drive the earlier realization of important, predictable and expected MPC benefits. [1, 11, 12]

OPERATING PROCEDURES DEVELOPMENT

It is a difficult task to develop accurate, realistic and credible operating procedures prior to start-up and commissioning. The task is even more difficult for critical emergency procedures.

Procedures available for start-up and commissioning are often vague, missing critical steps or worse case include errors and omissions that lead to unplanned incidents. As procedures are put into practice for the first time, the start-up and commissioning teams must learn to adapt on- the-fly.

Experienced start-up and commissioning teams quickly realized the OTS Digital Twin could be used as an effective and efficient tool for creating accurate, clear and complete procedures. These same procedures could also be fully exercised and improved during simulator testing and operator training. Users who developed accurate operator procedures using the OTS acknowledged the contribution from the same procedures towards their start-up benefits. (13)

ENGINEER AND OPERATOR TRAINING

The MPDS Digital Twin evolved from the use of dynamic simulation for OTS systems to provide a credible and rich training experience. Some OTS systems are justified and used solely to support start-up training of the new facility. Having delivered or exceeded the expected ROI, these systems are abandoned in their entirety following start-up.

Other uses understand the long-term value and maintain the OTS against a rigorous management of change process to ensure it continues to accurately reflect the real-world process for refresher and new-hire training. Lessons learned from process incidents and evolving industry best practices are then applied in new evolving training scenarios to ensure on-going safe and reliable operation. The same OTS also can be used to safely train operations support staff, such as process engineers and leadership, to provide them with operational experiences and a better understanding of the process operations, it's constraints and challenges. Both new and experienced employees benefit from on-going and regular exposure to the OTS as the only safe means to develop a broad collection of experiences operating the unit under a variety of conditions.

The value from using dynamic simulation models for training is well established and contributes to a suite of safety, reliability and operator effectiveness, productivity and performance benefits. Best-run facilities have learned to extract even more value from such training tools by integrating OTS training interventions into their competency management system. By connecting competency management to the capabilities of simulation-based learning scenarios, the company's training investments can be optimized, targeted and deployed to address specific competency gaps.

OPERATIONAL EXCELLENCE

During the operate and improve phase, the MPDS Digital Twin can be extended for purposes other than training. Process engineers can confidently use the dynamic model to evaluate the impact and benefits of various process changes or upgrades, such as debottlenecking studies, fine tuning operating procedures[14], resolving equipment constraints, etc.

Application engineers can use the Digital Twin to improve control and optimization strategies, test the impact of proposed changes to the automation systems and develop operator guidance and procedural automation applications. Maintenance staff can monitor equipment performance, comparing the simulator equipment performance with that of the real world.

Both dynamic and steady-state Digital Twins used in the engineering project can also be deployed for autonomous control applications, which can monitor and improve process and asset performance. The steady-state Digital Twin is applicable to process units or unit operations where propagation of unmeasured disturbances can impact the performance over the course of hours or days. Dynamic Digital Twins, on the other hand, are well suited to monitor performance and deliver insights for assets where the effects of process disturbances are quick, such as pumps, compressors, fired heaters and heat exchangers.

The combination of Digital Twins, data, machine learning and powerful analytics can support business and operational decisions that deliver incremental performance. Dynamic Digital Twins have been successfully used in real-time on-line process and equipment monitoring. Various techniques have been deployed, from comparing actual and simulated performance to tracking and accumulating the effect of slow process transients such as coking and fouling. Using dynamic Digital Twins in these applications provides awareness and details of equipment issues, the impact of current processing conditions on current and future performance and actionable insights for intelligent operations. Ultimately, on-line Digital Twins reveal opportunities for performance improvement which otherwise go unnoticed.

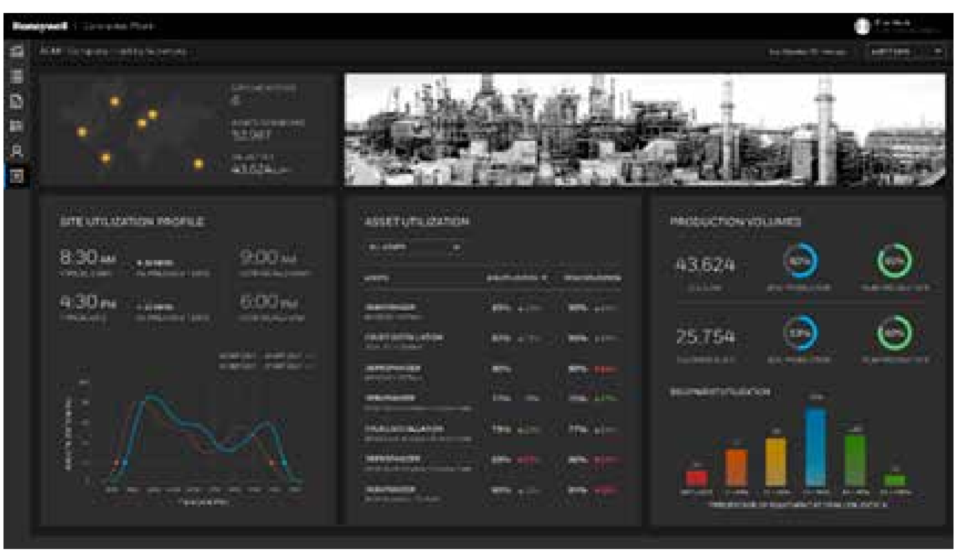
THE FUTURE

Although the application of dynamic Digital Twins has been extremely beneficial, there remains untapped continuous improvement opportunities in project execution and day-to-day operations, namely:

- The integration of automation and simulation workflow and
- Dynamic Digital Twins for analysis and decision making

When applying dynamic simulation for control and safety system validation, a best practice, which for many teams remains elusive, is effective integration of automation and simulation modelling workflows. As most of their work is on the critical path, the schedule distraction and unfamiliarity of each other's methodology becomes a barrier to effectively working together. The established practice maintains a separation between simulation and automation sequential execution plans. The simulation team continues to identify and share automation issues, but these are incidental and not their primary focus. The simulation team falls back on immediate fixes, workarounds, or other compromises to maintain schedule and on-time delivery. What happens then, in practice, is incomplete process control and safety system testing, leading to avoidable commissioning and start-up issues. Furthermore, the operator training simulation experience may be compromised as the experience may not be a complete accurate replication of the automation, safety system and HMI configuration.

The solution requires a closer look at the use dynamic Digital Twins in the development and delivery of a high-quality automation and safety system configuration. The key to delivering the value and benefits of the Digital Twin requires automation and engineering contractors to accept the role of dynamic simulation within their project workflows and for the simulation team to support an efficient iterative integration



of the same. The benefit of doing so will contribute to reducing project costs and improving project quality, both critically important requirements for the end user. The most important benefit accrued will be a high-quality control and safety system with well-trained process operators for a safe and flawless start-up. The application of the dynamic Digital Twin as an essential part of the automation workflow will generate project cost, start-up and commissioning savings that far exceed the complete investment in the OTS system.

Innovative vendors, partners and their end-user customers are applying dynamic Digital Twins as a key component of real-time digital transformation applications. The secure combination of data, analytics and Digital Twins for timely and relevant decision making provides business, operations and maintenance teams with new insights. When the Digital Twin is synchronized with its real-world counterpart, it provides a replication of the current conditions to compare current process performance to optimal performance. Integrated process and asset data, when combined with predictive analytics, can identify new levels of untapped productivity and insights to impending issues. Economic impact analysis of the opportunity helps prioritize actions to improve plant performance, operational efficiency, yield, and uptime.

CONCLUSION

> **Use of steady-state simulation in the project lifecycle is an established best practice. Dynamic simulation has also found acceptance and value by end users who have experienced high performance start-up and commissioning outcomes when an OTS was part of the project scope.**

The OTS was credited with the combination of well-trained operators and a fully vetted and exercised control and safety system in delivering flawless start-up and commissioning.

Those who immediately recognized the value of the dynamic Digital Twin expanded their use to serve a multitude of applications during the project and have acknowledged the incremental value delivered. They have specified the application of dynamic Digital Twins in capital projects as a firm requirement, strongly influencing various engineering team's workflow to accommodate the use.

Successful use of dynamic Digital Twin applications in project development is dependent on using simulation technology and related tools with the following key attributes:

- Robust high fidelity first principals based steady-state and real time dynamic simulation models within the same simulation platform and a common user experience
- Dynamic simulation tools that have a credible and realistic capability to connect to or simulate the actual real-world control and safety systems using native system configuration files without modification
- The OTS control and safety system integration activities, tools and work processes must be amenable to efficient integration with the iterative automation integration, testing and validation workflow
- Simulation technology must have a track record and clear vision of applying both a consistent set of tools and capabilities for both steady-state and dynamic Digital Twin models throughout the project, including autonomous analysis and decision making during the Operate and Improve phase

The benefits of dynamic Digital Twin applications are realized by:

- Right and fast capital expense savings through optimized equipment sizing and schedule improvement due to minimizing rework
- Higher quality project execution, that delivers flawless start-up and on-target operational performance capabilities with a competent operations staff and few latent design defects during start-up and commissioning
- Better day-to-day performance of the asset through a reduction in frequency and severity of abnormal situations via a safer and more stable processes, effective operating procedure and trained competent workforce
- Operational excellence that drives a culture of continuous improvements to proactively improve in real-time, reliability, productivity and performance

The dynamic Digital Twin is a key enabler in delivering high-performing process assets. The benefits are immediately realized via a safe and flawless start-up, and continue to accrue during the operate and improve phase. With the current focus on IIOT and digital transformation initiatives, the application of dynamic Digital Twins can substantially improve performance and the return on investment through efficient and realistic analysis and decision making for engineering, operations and maintenance.

REFERENCES

[1] Multi Purpose Dynamic Simulator (MPDS), an integrated simulation tool to support design and Flawless Start-Up. **Overtoomb, Peter J. de Kok and Rob R.M.** Qatar : s.n., March 5 - 7 2012. Proceedings of the 3rd International Gas Processing Symposium.

[2] Project Design and Process Control improvements by Dynamic Simulation of Transients. **Stefano Signor, Flavio Manenti, Maurizio Rovaglio and Andrea Merati.** s.l. : NTNU ICheaP8, 2007.

[3] **Barber, J. A.** Blowdown analysis delivers accurate results for depressurizing. Processing. December 2015.

[4] **Womack, J. W.** Dynamic simulation in the processing industries: case studies from Mobil experience. Modelling, Identification & Control. 1986, Vol. 6, 4.

[5] Combining Traditional UOP HAZP Analysis with Dynamic Simulation - A New Process Safety / Risk Assessment tool . **Wozniak, Bill Wiede & Scott UOP LLC, A Honeywell Company.** Honeywell Users Group; Europe, Middle East and Africa : s.n., 2015.

[6] **Dolph, Greg.** The use of Dynamic Simulation to Develop Control Strategies for Emergency Situations. Computers & Chemical Engineering. July 2000, Vol. 24, 2-7.

[7] **Herbig, Timothy.** Use Dynamic Simulation To Improve Process Safety. Chemical Processing. July, 2019.

[8] Rigorous Dynamic Simulation and Optimization for FCCU Absorption-Stabilization System. **Qi Pan, Enxi Lu and Juanjuan Li.** [ed.] European Symposium on Computer Adied Process Engineering. s.l. : Elsevier Scinence B.V., 2005.

[9] **Wang, G. Stephenson and L.** Dynamic Simulation of Liquified Natural Gas Processes: Here's How to Improve the Process Design and Operation of your Facility. Hydrocarbon Processing. 2018, July.

[10] **Luyben, William L.** Use of dynamic simulation for reactor safety analysis. Computers & Chemical Engineering. May 2012, 40.

[11] Integrated Process and Process Control Design of a PP-Splitter Using Dynamic Flowsheet Simulation and Shell Multivariable Optimising Control. J**.F.M.Van Dijk, S.De Wolf, R.Postma, L.C.Zullo, M.Guenin, P.H.Gustafson.** s.l. : IFAC Proceedings, 1994.

[12] Optimizing Diesel Production Using Advanced Process Control and Dynamic Simulation. **Marcio R. S. Garcia, Renato N. Pitta, Gilvan G. Fischer and Eneas R. N. Neto.** Cape Town, South Africa : The International Federation of Automatic Control, 2014. 19th World Congress.

[13] Operating Procedure Analysis with Consequence Prediction by Dynamic Simulation. **Richmond, Y. Fang and P.C.** s.l. : 9th AIChE Soutwest Process technology Conference, 2017.

[14] **Richmond, M. A. K. Rasel and P. C.** Improve Safety and Reliability with Dynamic Simulation. s.l. : Wiley Online Library (wileyonlinelibrary.com), 2014.

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