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GAS PROCESSING
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**CAPITAL PROJECTS**

**CATALYST SELECTION** ECONOMICS

INCREASING **NEEDLE COKE YIELDS**

**FCC UNIT** TROUBLESHOOTING

# Future refinery complexes built using an integrated approach

## Minimise risks of project design changes at later stages using process digital twins during the design phase

Amit Sarna and Sachin Srivastava
**KBC**

The refining industry is going through unprecedented times. Industry players are confronted by numerous challenges, including volatile crude prices, diminishing demand for transportation fuel, and stringent regulations to meet decarbonisation targets to produce cleaner fuels. At the same time, the growing economies in Asia will continue to propel the demand for petrochemicals. The future comprises a world of fuel refineries, refinery-integrated petrochemical complexes, and crude oil to chemicals. Through this energy transition, the latter two will undoubtedly be more resilient toward future demand and supply-side dynamics.

With the increasing complexity and size of investment for new capital projects, owners are seeking holistic technical and operational guidance to make better investment decisions and minimise costly rework with EPC (engineering, procurement, and construction). As shown in **Figure 1**, a conventional project execution approach requires information sharing amongst different advisors through various project phases. During each transition, there is often productivity and information loss, resulting in project scope and schedule overrun.

Initial study phases of capital projects are critical and, despite constituting a small portion of the total project costs, they can potentially reduce overall project costs by up to 20% and improve integrated complex margins by USD 2 to 3 per barrel of crude. The owner's project team often has limited subject matter expertise and skills to cover these aspects. The concept of an owner's technical advisor (OTA) for capital projects is increasingly becoming common to address such gaps with respect to technical, operational, and organisational experience.

With a large multi-disciplined project, the owner may enlist the assistance of third parties to review the project aim and objectives as well as basic engineering. A PMC may be engaged to help guide and manage the efforts of other contractors. In addition, licensors used for each specific technology are intertwined in the project. The interaction of the owner, PMC, and licensors require an understanding of the multiple aspects of the project. In this conventional approach, licensors work in silos where their focus gets restricted to the unit inside the battery limit.

Meanwhile, the PMC focuses on other interfaces and drives the schedule/cost optimisation. In this way, the focus on the overall complex-wide optimisation and integration is compromised. The OTA's role is to provide the owner with an independent review and analysis to keep the project's goals and objectives as the focal point. The OTA bridges the goals and objectives between different owner groups and appointed agencies (licensors, EPC, PMC) into a more efficient and streamlined process, as depicted in **Figure 2**.

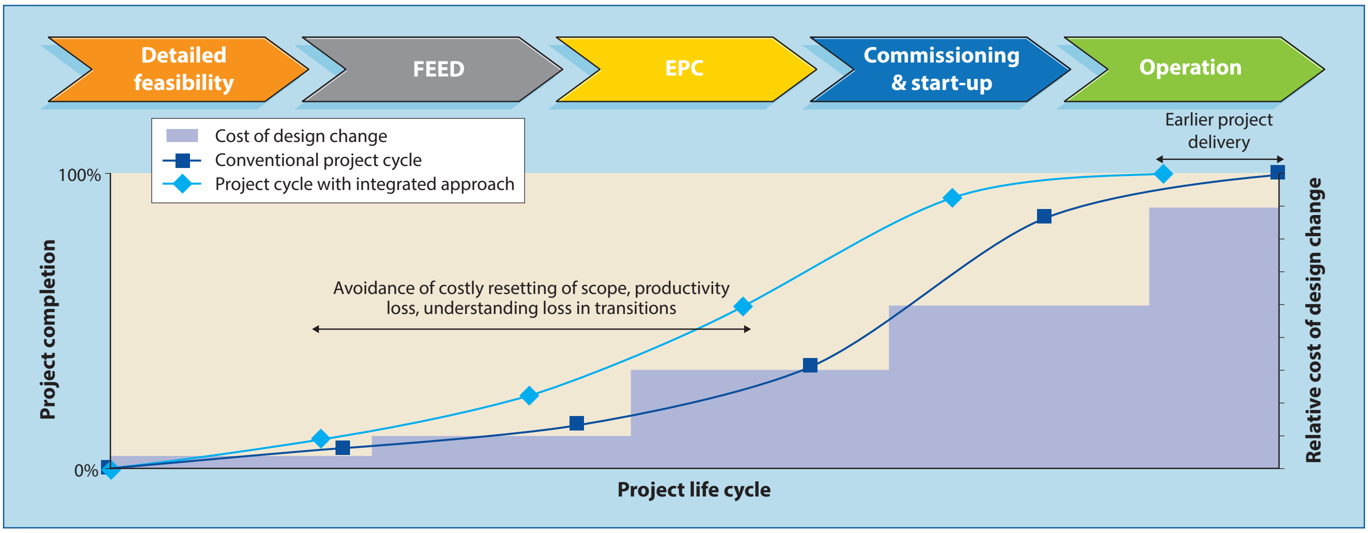


**Figure 1** Project life cycle using conventional vs an integrated approach

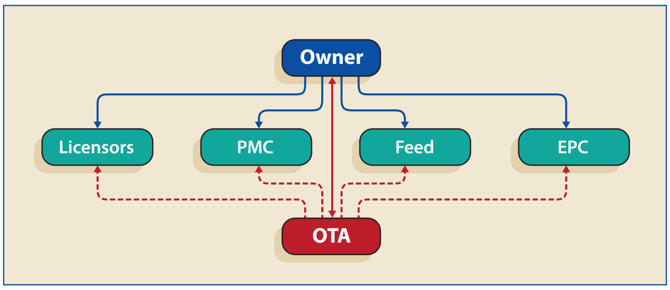


**Figure 2** Project organisation with integration of an OTA

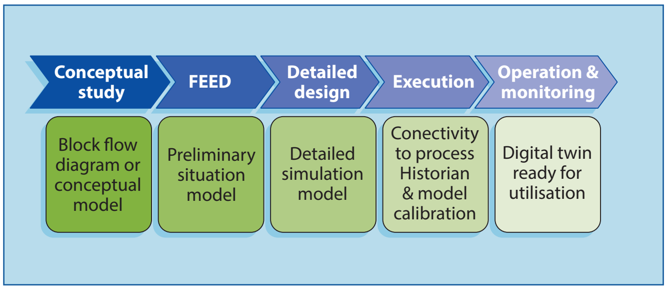


**Figure 3** Evolution of process digital twin during the project life

This includes analysing critical concerns in the early stages of the project; reviewing licensor packages and optimising all licensed units; optimising utility consumption of all process units; solving issues outside of the licensor remit, such as various operation scenarios and turnaround issues to protect the owner's objective. The OTA provides a holistic view and develops an integrated approach using subject matter expertise for various technologies supplemented with rigorous simulation modeling tools. Additionally, the OTA integrates into the owner's team, allowing seamless knowledge transfer to the owner's project and operating teams for building long-term capabilities. The OTA's critical insights run across unit and system boundaries to ensure proper integration at the different interfaces to minimise recycling work at later stages, which helps bring significant cost savings and schedule delays at later stages of the project.

As an OTA, KBC employs an integrated approach based on three pillars: subject matter expertise, proven methodologies, and robust tools, such as process digital twins. The KBC Petro-SIM process digital twin is a complex-wide rigorous simulation model that builds kinetic reactor models for all process units across the enterprise. A digital twin is useful across the asset's entire lifecycle, as shown in **Figure 3**.

Ideally, it should be created during the initial study to evaluate the feasibility and process model of the asset. During the design and EPC phases, the digital twin is used and further developed to facilitate the most optimal design of the asset as well as training its operators. Furthermore, it can be used to optimise and predict maintenance during the bulk of a plant's lifecycle, operation, and maintenance.

A complex-wide process digital twin is used for several key activities during the design stage of a project. Following are some key uses of a complex-wide digital twin during the project stage:

## Improved design definition

Traditionally, linear programming (LP) models have been used to derive key stream flows and quality information to determine the basis of process unit design. The limitation of this method often results in inaccurate feed definitions and other critical information. A rigorous complex-wide digital twin can close this gap and ensure a robust foundation for process design by providing better stream property definition for design.

## Updating the LP model

The LP model at the feasibility stage typically marginalises the definition and is generally built with a fit-for-purpose approach using limited unit parameters in a sub-model representation. The same model can be upgraded with relevant parameters for each unit based on the selected licensor data. When the tuned digital twin model is calibrated using the licensor data, it can generate accurate LP vectors to predict the right response about feed quality or operating parameter changes.

The updated LP model can be used for various optimisation sensitivity studies related to feedstock selection and operational mode changes. By conducting these sensitivity studies, the owner can identify unit operating and blending constraints at the design stage and provide the required design cushion to process different operating scenarios and opportunity feeds.

**Order of preference**

High preference → Low preference

| | | | | | |
|---|---|---|---|---|---|
| $C_3$ | SC | LPG | | | |
| $C_4$ | SC | MS | LPG | | |
| $C_5$ | SC | ISOM | MS | | |
| $C_6$ P | SC | ISOM | MS | CCR PX | CCR MS |
| $C_6$ N and A | SC | CCR PX | MS | CCR MS | ISOM |
| $C_7$ | SC | CCR PX | CCR MS | MS | ATF/HSD |
| $C_8$ | CCR PX | SC | CCR MS | ATF/HSD | |
| $C_9$ | CCR PX | SC | CCR MS | ATF/HSD | |
| $C_{10}$+ | SC | ATF/HSD | | | |

**SC** – Steam cracker
**MS** – Gasoline
**ISOM** – Isomerisation unit
**CCR PX** – Naphtha reformer for p-xylene
**CCR MS** – Naphtha reformer for gasoline
**ATF / HSD** – Jet or diesel

**Figure 4** Typical feed preference and selection criteria

## Integrated complex optimisation

The potential from incremental improvement with increased conversion capabilities of a fuel refinery with added petrochemical integration is USD 1.5 to 2 per bbl of processed crude. The value gained from effective molecular management is significant. **Figure 4** shows the typical feed preference and selection criteria for key refineries and petrochemical processes.

A rigorous complex-wide process digital twin enables effective molecular management at the design stage by providing detailed carbon number breakdowns from crude assays through blending and petrochemical units for the whole integrated complex. These enhanced capabilities allow site-wide optimisation opportunities to be identified across the integrated complex. Such opportunities can be easily implemented at the design stage and lead to improved project economics.

## Steam and power system optimisation

Refineries and petrochemical facilities face increasing pressure from regulators to decarbonise their current and future facilities. KBC includes the complex-wide steam and power system optimisation with net zero vision (see **Figure 5**). Using this model with KBC's proprietary Best Technology methodology for energy optimisation, a holistic analysis is performed to optimise the entire system and identify energy-saving opportunities for each process unit. Thus, the complex saves energy and enjoys higher cash margins. Additionally, improving energy efficiency is the most cost-effective way to mitigate $CO_2$. Reducing $CO_2$ emissions also reduces the capital investment required for carbon capture facilities.

## Scenario analysis

Off-design cases, such as start-ups, ramp-up, feed and operating mode change, are often not evaluated as part of a complex design and may result in unforeseen challenges and delays during operation. Such delays can result in severe economic penalties. The complex-wide flowsheet can be used to analyse such scenarios to identify critical constraints and plan mitigation strategies in a timely manner.

## Case study

KBC served as an OTA for an Asian company planning to build a grassroots refinery-petrochemical complex. KBC's SMEs were integrated with the owner's team after the detailed feasibility study for the complex was completed. As an OTA, KBC evaluated licensor evaluation and selection, reviewed licensor basic engineering and design packages, and participated in various critical meetings with licensors, PMCs, and vendors.

Using information from technology licensors in the Petro-SIM simulator, a rigorous digital twin for the whole complex was developed. A process digital twin was then used to evaluate several opportunities for margin improvement and energy conservation. As a result of these opportunities, refinery margins exceeded 10%. Compared to the base case, the complex overall energy consumption was reduced by roughly 6%. Key improvements included:

- Feedstock optimisation
- Improved feed definition
- Refinery-petrochemical value chain maximisation
- Gasoline blend feasibility
- Steam and power system optimisation
- Complex turnaround optimisation

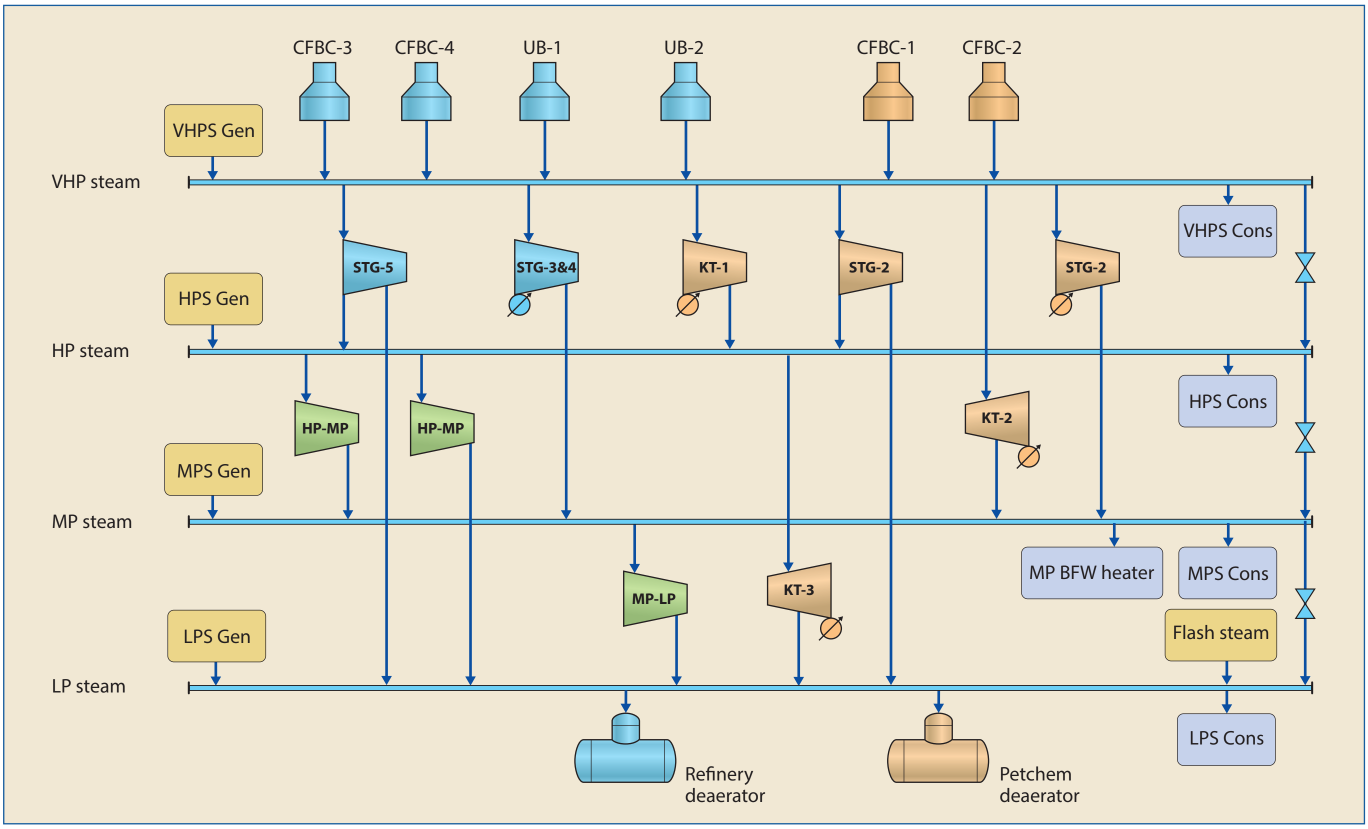


**Figure 5** Petro-SIM Model for complex-wide steam and power network

**Feedstock optimisation** A refiner requested co-processing of an indigenous crude along with an imported crude mix for design purposes. However, these crudes had very different paraffin and aromatic content, which may have caused crude compatibility issues and could lead to asphaltene precipitation in crude pipelines and furnaces. The Petro-SIM digital twin was used to determine the maximum amount of indigenous crude that could be safely co-processed with imported crude blends. Furthermore, the overall crude blend was optimised, resulting in additional benefits of about USD 0.6 per bbl.

**Improved feed definition** A process digital twin helps predict rigorous and accurate intermediate stream properties based on the crude assay data and provides improved feed quality predictions for the conversion and treatment unit. A unit process digital twin was used to predict the vacuum gas oil (VGO) hydrotreater feed quality, considering deep cut VGO. The LP model predicted very conservative responses to feed distillation change in terms of key feed qualities (e.g., nitrogen, metals, and Conradson Carbon [CCR]), which would have caused catalyst life design issues. The model prediction helped design the right catalyst volume and reactor LHSV to process difficult feed.

**Refinery-petrochemical value maximisation** The margin improvement studies revealed an opportunity to process kerosene as feed to the steam cracker to produce higher petrochemical products instead of blending it with diesel, resulting in an overall improvement of nearly USD 1 per bbl. Proper design considerations were taken at the design stage to process kerosene in the steam cracker. KBC highlighted key challenges and their mitigations to process kerosene feed to steam crackers, which included the addition of impurities removal systems and increasing the capacities of heavier end processing.

**Gasoline blend feasibility** A process digital twin was used in the feasibility stage to identify the infeasibility of the gasoline blend. This was primarily due to higher aromatic quantities from certain gasoline blend streams, which were improperly captured in the LP model. Further, the model was used to evaluate the maximum gasoline that could be made with the available streams. Furthermore, additional facilities were considered in the design to address the requirement for the imported blendstock to meet the full gasoline target as per the required specifications.

**Steam and power system optimisation** Originally, proposed power plant configurations included power generation through several condensing steam turbine generators (STGs). Similarly, there were condensing turbines considered for critical drives in process plants. Our SMEs reviewed the overall system and proposed using a more efficient motor drive. In addition, the whole steam and power generation system was optimised using the energy digital twin, resulting in significant energy, Capex, and operating cost savings.

**Complex turnaround optimisation** Our SMEs evaluated the proposed turnaround philosophy considering all applicable scenarios and optimised it based on global benchmarks and best practices. This resulted in eliminating and reducing the sizes of several tanks that were part of the original philosophy. Consequently, Capex was reduced by nearly 3% of the total project cost.

## Conclusion

A refinery and petrochemical integrated project requires substantial capital investment. Once completed, they face several challenges such as fluctuating feedstock and product prices, as well as regulatory and environmental changes. All these uncertainties make it necessary for projects to be completed within the planned budget and schedule. The traditional approach and tools used during the early stages of these projects must be revisited because of the ever-increasing scale and complexity of these integrated refinery-petrochemical complexes.

The OTA brings an independent perspective and global experience from working on similar technologies and projects worldwide. Helping owners set global- and unit-level objectives ensures all key stakeholders are aligned with project goals. It is important that the OTA deploys a methodology combining subject matter expertise with rigorous tools to validate assumptions.

Such a methodology is essential to minimise the risks of design changes at later stages of the project. By using process digital twins during the design stage, optimisation opportunities and critical constraints can be identified and modified accordingly. Additionally, the OTA can mitigate any skill gaps within the owner's team while enhancing capability via training and sharing process knowledge and best practices.

As an OTA during licensor selection and design review, KBC has improved profitability and reduced capital cost across the entire lifecycle of refineries and petrochemical complexes. Lastly, its proprietary Profit Improvement Program optimises the yield and energy of operating facilities. Combining this experience with robust technology and tools can help owners achieve these goals.

**Amit Sarna** is a Principal Consultant with KBC Advanced Technologies Private ltd, heading the KBC India operations and supporting the consulting business line in KBC. He has more than 27 years of global experience in areas of feasibility and configuration studies, refinery petrochemical integration, profit improvement projects, revamp and asset optimisation studies. He holds a bachelor's degree in chemical engineering from Indian Institute of Technology B.H.U.
*Email: amit.sarna@kbc.global*

**Sachin Srivastava** is a Senior Consultant at KBC and is involved with KBC's consulting practice. He has more than 13 years of experience as an ethylene technology specialist across functions including operations, technical services, and capital project support. He holds a bachelor's degree in chemical engineering from Indian Institute of Technology, Kanpur.
*Email: sachin.srivastava@kbc.global*