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A Digital Scheduling Hub for Natural Gas Processing: a Petrobras Case-Study Using Rigorous Process Simulation

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ABSTRACT

To address the dynamic operational demands of the gas processing sector, which is continuously evolving due to gas market opening, increase in natural gas production, and the growing challenge of upstream-midstream integration in a competitive environment, this work presents the Integrated-Gas-Scheduling-System, IntegraGAS. The proposed methodology innovates by using first principles rigorous process simulation coupled with a scheduling tool for short/medium/long-term, enabling gas plants to swiftly adapt to varying operational conditions and meet the requirements of this new market. IntegraGAS was implemented in Petrobras and has significantly enhanced scheduling efficiency, reducing execution time by up to 99.2% and avoiding approx. US$ 2.3 million in annual labor costs, optimizing resource utilization. By integrating Excel for the frontend, Aspen HYSYS for process simulation, VBA for automation, and Microsoft PowerBI for real-time data visualization, IntegraGAS improves decision-making, regulatory compliance, and operational agility. Its key functionalities include alerts for operational limit violations, automated mass and energy balance calculations, optimized gas allocation, integration with maintenance shutdown plans and KPI monitoring. With an intuitive interface and a robust architecture driven by digital transformation, IntegraGAS eliminates manual inefficiencies, ensures seamless coordination among stakeholders, and enables rapid responses to market dynamics.

Keywords: Scheduling, Modelling and Simulations, Natural Gas, Planning, Planning & Scheduling, additional keywords separated by commas

INTRODUCTION AND OBJECTIVES

Natural gas processing plays a pivotal role in the oil and gas production chain, being responsible for treating the raw gas and separating impurities that can impair product quality [1]. This process not only ensures that gas meets the standards for end-use, but also maximizes production efficiency and resource value. Furthermore, in the context of global energy transition, natural gas is gaining increasing relevance due to its ability to function as an intermediary energy source — cleaner than oil and coal, yet still essential to meet global energy demand while renewable alternatives are not fully viable [1, 2].

In Brazil, the importance of natural gas processing has been further accentuated by the development of pre-salt reserves, where the high gas-oil ratio is a challenge, creating a need for advanced infrastructure for its processing and commercialization. This gas must be separated and appropriately treated before being transported or utilized. Therefore, the increase in natural gas production demands efficient and innovative solutions, both to optimize industrial operations and to ensure competitiveness in the global energy market.

The opening of the gas market in Brazil, driven by recent regulatory reforms, has marked a significant change in the country's energy sector [3]. With the approval of Law 11.909/2009, all companies gained access to gas transportation and processing infrastructure, previously restricted to the owner of the processing facility. This move aims to increase competitiveness, reduce gas costs, stimulate investments in new infrastructure and contribute to the diversification of supply sources, which is essential for national energy security [3, 4]. This new framework thus yielded a more dynamic, fast-paced and complex multi-party environment.

Gas market opening has introduced new operational and logistic challenges, particularly regarding management and scheduling of gas processing and its products. Previously centralized within a single player, scheduling now involves a multitude of stakeholders with varying demands and priorities. The complexity has increased as each economic actor requires dynamic and efficient management to handle its products, ensure contract compliance, transport optimization, cost management and adherence to regulatory standards [3, 4].

In this context, scheduling of natural gas processing plants has become a critical process, as production planning needs to be frequently adjusted to meet variable demand while simultaneously optimizing resources. The need to perform detailed and accurate simulations to manage multiple scenarios, involving variables such as gas flowrates, processing capacity and contractual requirements, calls for more elaborated tools [3, 4].

Whereas traditional works on chemical production scheduling rely on simplified models (linearized versions of highly nonlinear systems and/or recovery factors) [7] and do not consider key process variables such as flows, compositions and temperatures [7], this is no longer sufficient to address the complexity of this new context. This work intends to fill this gap by proposing an innovative integrated first principles scheduling methodology and applying it into a digital-based tool for industrial application. Throughout this article, the details of IntegraGAS implementation at Petrobras, observed benefits, and its contributions to the digital transformation of the natural gas sector will be explored.

METHODOLOGY

To reach the objective of this work, a practical case study was chosen for proof of concept and industrial application: Petrobras integrated natural gas processing assets. IntegraGAS was developed, tested and applied at each gas asset for: plant modeling, automation, integration and management of the scheduling processes. The next subsections will cover details on the case-study system, plant modeling and computational aspects that yielded IntegraGAS.

System Description

The system in study consists of four industrial gas processing assets: UTGC, UTGCA, UTGCAB and UTGITB. They are part of Petrobras natural gas processing area, which is illustrated in Figure 1. In each of those midstream assets, three main scheduling processes are carried out; they vary in time-horizon, level of detail required from planning and frequency, as detailed in Table 1.

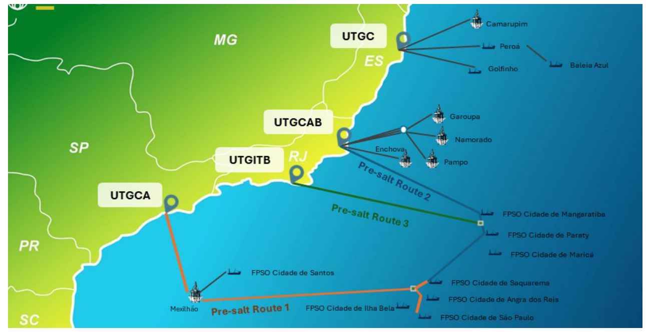

Figure 1. Illustration of Petrobras integrated natural gas processing system, showing the connections between upstream and midstream (UTGC, UTGCA, UTGCAB, UTGITB) facilities along Brazil coast.

Table 1: The three scheduling processes that are considered in this work. Details include the number of simulation scenarios, time basis and frequency of each of them.

Time horizon	Simulation scenarios	Time basis	Frequency
Short	30	days	daily
	92	days	monthly
Medium	15	months	monthly
Long	12	months	annually
	15	years	annually

Plant Modeling

Unlike most scheduling tools [7], this work chose a first principles rigorous approach for plant modeling. This decision was based on business evaluation, considering that the requirements of this new dynamic market scenario are not anymore satisfied by classic simplified approaches, such as recovery factors and linear models.

Aspen HYSYS was the commercial simulator chosen for all plant modeling, due to its widespread usage and peer-recognition for natural gas processing simulation. Every asset had its specific first-principles process model, as illustrated in Figure 2. Each model was developed in the light of the current official plant Process Flow Diagrams (PFDs), allowing for rigorous and accurate representation of the industrial asset as well as for easy verification and third-party auditing of the model and its results. Proper model validation was then carried out along with the plant Operations team, by comparing product flowrate outputs, per model, against actual data.

The simulations were specifically tailored for scheduling application, ensuring appropriate compromise between model fit, execution time and open-market transparency requirements. Also, an extensive engineering work was carried out on mapping key process plant variables, i.e. the ones to which production scheduling was

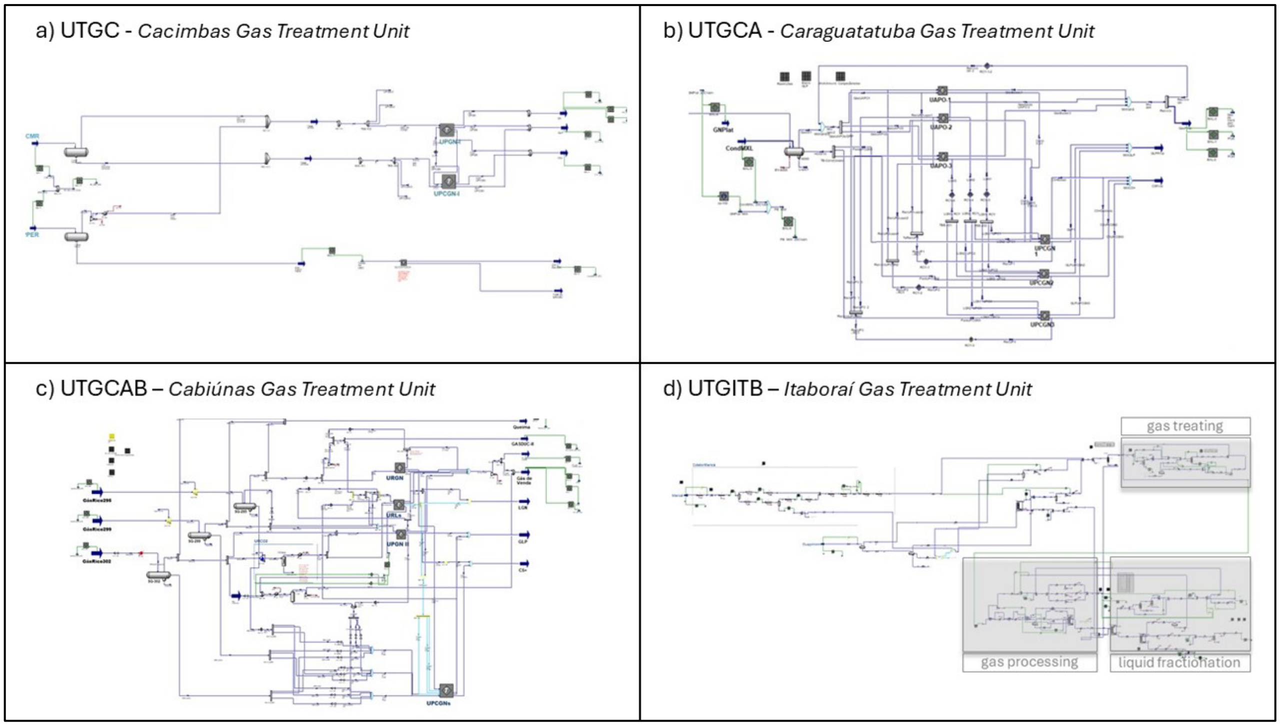

Figure 2. Representation of the main flowsheet from Aspen HYSYS simulation model of UTGC (a), UTGCA (b), UTGCAB (c) and UTGITB (d).

the most sensitive and adding them as frontend user inputs (manipulated variables at IntegraGAS) in two levels: a) main and b) specific.

Computational aspects

Architecture

IntegraGAS architecture was conceived based on the following business goals: (1) plant modeling should be rigorous and executed on recognized commercial process simulator; (2) interface and usability should be user-friendly and easy for Process Engineers to adapt, thus increasing software adoption; (3) software maintainability and improvement should be easy and fast to implement, in accordance with business dynamics.

Based on these criteria, IntegraGAS architecture used Microsoft Excel for the frontend, VBA (Visual Basic for Applications) for engine calculations and an OLE connection between VBA and Aspen HYSYS to enable automated rigorous process simulation, as seen in Figure 3.

From Figure 3, it is important to emphasize that IntegraGAS connection with plant modeling was such that HYSYS simulation files stay totally transparent to the end user, who interacts only with the application frontend (Excel). Thus, while IntegraGAS robustly guarantees accurate and rigorous process simulation results, it is not necessary for the end user to be familiar with HYSYS, keeping the access to IntegraGAS simple and easy to use throughout a wide range of users from the gas plants. This is especially important for this application, since the short-time scheduling process is required by contract to be executed every day, even on weekends; this means that different shifts will be working to meet this process.

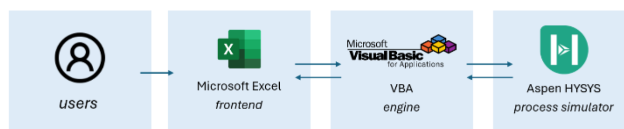

Figure 3. IntegraGAS architecture made in this work.

Features

IntegraGAS is organized into three main sections, designed to address the scheduling processes detailed in Table 1. Each section incorporates functionalities that enhance user efficiency and ensure seamless integration with operational workflows:

1. **Data input:** streamlines the collection and consolidation of raw gas data by integrating information from various processes, systems, and departments through standardized Excel spreadsheets. This feature reduces manual data handling errors and ensures consistency across dataflow.
2. **Simulation environment:** offers an intuitive and dynamic workspace to: a) configure multiple scenarios by adjusting key manipulated variables, enabling flexible *what-if* analyses; b) execute rigorous process simulations with speed and accuracy; c) analyze detailed results and turn them into actionable

insights for business planning and decision-making.
3. **Scheduling export**: automates the generation and export of production planning results tailored to short-, medium-, and long-term needs, facilitating seamless interaction between teams and systems.

User Interface and Engine

IntegraGAS frontend uses Microsoft Excel due to its familiarity among process engineers, enabling smooth adoption and seamless integration into daily workflows. Excel's intuitive interface simplifies data input, scenario configuration and result analysis without requiring additional training or specialized software expertise.

The engine, built in VBA, connects directly to Aspen HYSYS simulations, offering:

1. **Flexibility:** Custom functionalities tailored to plant-specific needs.
2. **Dynamic Updates:** Easy fit to plant modifications, business demands, and new scheduling methods.
3. **Automation:** Streamlined calculations and integration with first-principles HYSYS models, ensuring accuracy with minimal manual effort.

The interface is designed for simplicity and efficiency, featuring well-structured Excel worksheets with drop-down menus, conditional formatting, and automated alerts. This reduces cognitive load and allows engineers to focus on optimizing production plans and evaluating scenarios.

Information Security

In all sections of IntegraGAS the appropriate information security measures are applied. This means that the user does not manipulate the input/output data at any time nor has editing privileges to alter any of these numbers after the input/output procedure is complete, since the tool is password protected and only the development team has admin privileges. This guarantees a secure and reliable dataflow, a primary requirement for this application in case of auditing or questioning by third parties.

Operation aspects

To further enhance usability and reliability, IntegraGAS included a suite of advanced features focusing on operation performance:

1. **Automatic Alerts:** Notifications for operational limit violations and convergence status, ensuring compliance with safety and performance standards.
2. **Data Consistency Checks:** Built-in validation mechanisms to identify and correct inconsistencies in input data before simulation.
3. **Mass and Energy Balance Calculations:** Automated balances ensure all simulations maintain physical accuracy and adhere to process constraints.
4. **Integration with Shutdown Plans:** Synchronizes scheduling with planned maintenance activities to minimize downtime and operational disruptions.
5. **Automated Gas Allocation:** Streamlines the distribution of processed gas, including calculations for flaring and fuel gas, to optimize resource utilization.
6. **KPIs:** Calculation and graphical display of the main business key performance indicators of each asset.

Moreover, by combining advanced modeling capabilities with a user-friendly interface, IntegraGAS not only simplifies complex scheduling tasks but also empowers process engineers to focus on strategic decision-making. The robust architecture and automation reduce manual effort, enhance operational accuracy and support plants in achieving optimal performance with minimal downtime.

RESULTS AND DISCUSSION

Plant Modeling

Plant simulations were carried out in Aspen HYSYS v11/v14. Each model was validated against actual plant history data and showed good fit, with deviations under 10 % – the validation results and methodology followed previous literature works from the same research group [5, 6], where further details can be found on the model.

Computational aspects

Features: development and gains

The main features that were created specifically for IntegraGAS are shown in Figure 4, which gather multiple screenshots from the tool Main Dashboard (a) and Simulation Environment (b). This structure aimed to fulfill the requirements mapped in Table 1 besides making the scheduling process easy to be conducted. They are reflected in the three sections of the Main Dashboard (Figure 4.a): short-term (a.1), medium-term (a.2) and long-term (a.3). For each, the main features are:

1. **Data input:** Represented by the yellow buttons in Figure 4a. Collects data via VBA code. Data refers to the plant inlet gas stream, per entry point, at 20 ºC and 1 atm, mole composition, temperature and pressure. IntegraGAS collects information from those files, manipulates them and presents to the user in a friendly and easy-to-interpret layout (shown in Figure 4b.2).
2. **Simulation environment (Figure 4b):** The process engineering core of IntegraGAS. It is the main hub from where user defines the main manipulated variables (Figure 4b.3), configures and executes simulations (Figure 4b.1), and analyzes input/output data (Figure 4b.1/b.4). Allows for automatized multi-case execution of simulation scenarios (Figure 4b.1) and performs input data checking (Figure 4b.1).
3. **Scheduling export:** Represented by the yellow buttons in Figure 4a. Generates structured planning output, fitted to the scheduling process under execution. Exports the results as an Excel file and saves

it in a user-selected folder.

Those implemented features yielded several gains. The main were, per feature: (1) secure and seamless data flow; information integrity and consistency between gas plants, (2) centralized information from different sources in one environment, reducing manual data handling; easy manipulation of plant simulation from Excel frontend, even for users without HYSYS experience; multi-case execution of simulations in one go; easy data checking and error identification, (3) automatic file generation in standard layout, reducing labor expense and human errors.

Execution time

By automatizing the process, one of the major gains was on the reduction of total execution time to generate planning results. The manual approach required several data handling, manipulation and one-by-one input in the HYSYS simulation files. This process was extremely laborious and inefficient – IntegraGAS approach was up to 125 times faster, as seen in the numbers from Table 2.

Performance Gains: Business aspects

The expressive reduction in execution time, discussed in the previous section, yielded a direct gain for business: lower labour cost and resource optimization. With this time saving, plant Process Engineers can focus on more specialized tasks, such as results analysis, process investigation and plant optimization.

For instance, considering only the short-term scheduling, a total of 992 process simulations are executed per month, per gas asset – or 11'904 per year. Considering the reduction in execution time (Table 2) and a reference labour cost of US$ 53.9 per working hour (Bureau of Labor Statistics), IntegraGAS is returning a total savings of US$ 2.3 million per year for Petrobras natural gas processing sector. Still adds to this number the potential gains for medium- and long-term scheduling.

Petrobras Natural Gas Strategic Plan

IntegraGAS did also cover the main scheduling process in Petrobras: Annual Strategic Plan. This process is key for being highly strategic for long-term business decisions – and consequently demands a high level of interaction and flow of information with other systems and business departments, such as: Strategy, Performance, Logistics, Marketing, Commercialization and Upstream/Midstream Operations.

IntegraGAS was successfully used in Petrobras Natural Gas Strategic Planning 2025-2029, conveying a

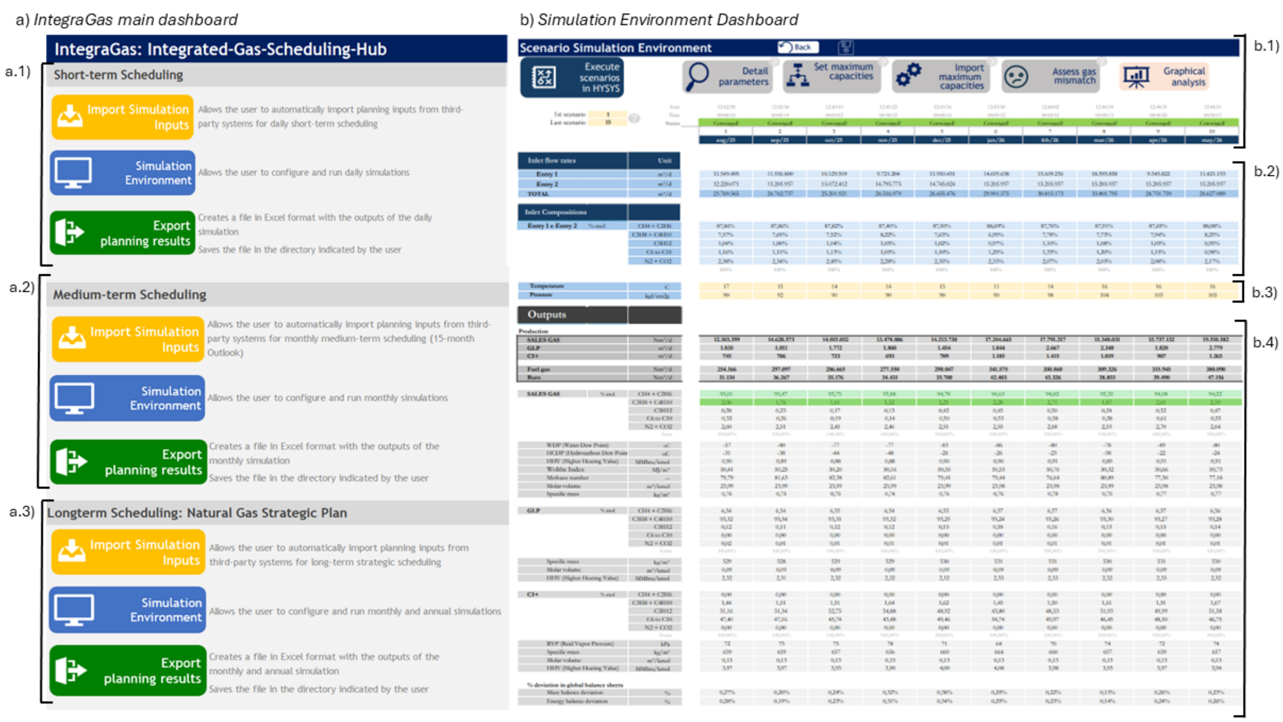

Figure 4. a) Main dashboard in Excel, where desired planning is chosen: **a.1)** short-, **a.2**) medium-, or **a.3)** long-term. Each has three features (buttons): input data import (yellow), access to the Simulation Environment Dashboard (blue) and export of simulated results (green). **b)** Simulation Environment Dashboard, where users can analyze and simulate data: **b.1)** Dedicated buttons to additional functionalities. Displays simulation times and convergence status. **b.2)** Input data such as flowrates and compositions, marked in blue. **b.3)** User-manipulated variables, marked in yellow. **b.4**) Simulation results, marked in gray, including mass and energy balances.

seamless functionality that integrated all this scattered information and yielded consistent and reliable results for proper decision-making on investment analysis and strategic planning. Also, by providing structured input and output results, IntegraGAS enabled the development of a Business Intelligence (BI) layer for data visualization, making strategic data readily available online across departments, thus reducing time spent on data handling and information sharing, as well as ensuring proper information security, access control and data levelling.

Table 2: Comparison between planning execution time with manual and IntegraGAS approaches, by gas asset.

Asset	Execution time (min)	
	manual	**IntegraGAS**
UTGC	50	0.8
UTGCA	50	0.4
UTGCAB	50	2
UTGITB	50	1

Visual Identity

A logo (Figure 5) was created to strengthen IntegraGAS identity and symbolize departmental integration for optimizing gas processing.

Figure 5. IntegraGAS logo created by this work.

CONCLUSIONS AND FUTURE WORKS

This work intended to propose a novel approach for production scheduling, utilizing the implementation of a digital-based tool (IntegraGAS) in four assets of Petrobras natural gas processing sector as case study. IntegraGAS architecture used Excel for frontend, VBA for engine and direct OLE communication between VBA and Aspen HYSYS – this facilitated software retention by end users, who are familiar with Excel applications. The most distinguishing and innovative feature of this approach is the transparent use of first principles rigorous simulation for plant modeling, what guarantees consistent, verifiable and reliable simulation results – key requirements of the multi-party open gas market scenario – while being transparent to the end user. The implementation of IntegraGAS was successful and it has been in use in the industry since 2022, with hundreds of thousands of simulations successfully executed so far, considering short-, medium-, and long-term planning.

This work contributed to the literature by successfully developing, implementing and testing a novel first-principles integrated scheduling tool, with industrial application, that delivered rigorously accurate yet fast, auditable and reliable automated results. For future works, the suggestion is to develop a higher-level decision layer, by integrating upstream and midstream planning as a single system (Figure 1), thus opening the path for unified planning and optimization studies.

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REFERENCES

1. S. Faramawy, T. Zaki, A.A.-E. Sakr, Natural gas origin, composition, and processing: A review, Journal of Natural Gas Science and Engineering, Volume 34, Pages 34-54, (2016). https://doi.org/10.1016/j.jngse.2016.06.030
2. Mokhatab, S., Poe, W. A., & Mak, J. Y., Handbook of natural gas transmission and processing: principles and practices. Gulf professional publishing, (2018).
3. dos Santos, E. M., Peyerl, D., & Netto, A. L. A., Opportunities and Challenges of Natural Gas and Liquefied Natural Gas, Ed. Letra Capital, ISBN: 978-65-87594-44-6, (2020).
4. Ferraro, M. C, Hallack, M., The development of the natural gas transportation network in Brazil: Recent changes to the gas law and its role in co-ordinating new investments, Energy Policy, Volume 50, Pages 601-612, ISSN 0301-4215, (2012). https://doi.org/10.1016/j.enpol.2012.07.063.
5. Souza, T.E.G. et al. Modeling and economic optimization of an industrial site for natural gas processing: a nonlinear optimization approach. Digital Chemical Engineering, 6, 100070. (2023). https://doi.org/10.1016/j.dche.2022.100070
6. Souza, T.E.G. et al. Modeling and economic optimization of an industrial site for natural gas processing: an MINLP approach. Computer Aided Chemical Engineering, 53, 3307-3312. (2024). https://doi.org/10.1016/B978-0-443-28824-1.50552-4
7. Harjunkoski, I. et al. Scope for industrial applications of production scheduling models and solution methods. Computers and Chemical Engineering, 62, 161-193. (2014).