CoPro: Coordinated Production for Better Resource Efficiency

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Better coordination of production means improved energy and resource efficiency.

Individual units often are already automated and operated efficiently.

Inefficiencies result from lack of coordination.
CoPro: Short fact sheet

- Full title: Improvement of Energy and Resource Efficiency by Better Coordination of Production in the Process Industries
- Contributes to circular economy and industrial symbiosis
- Builds on the results of FP7 projects
  - MORE: Real-Time Monitoring and Optimisation of Resource Efficiency in Integrated Processing Plants
  - DYMASOS: Dynamic Management of Physically Coupled Systems of Systems
- 17 partners from 8 countries
- Duration: 42 months
- EC contribution: 6 M€
Consortium

Industry with 5 applications covering the complete value chain

Technology providing SMEs

Universities

Dissemination and exploitation support

Research institutes
Mission

Improved coordination is key to better energy and resource efficiency of the existing assets

CoPro addresses coordination in three dimensions:

- **Cross-layer process integration**: Integration from basic process controls to the coordination of the supply chain
- **Cross-unit and cross-plant coordination**: Integrated management and control of heterogeneous units coupled by flows of energy and materials
- **Cross-functional coordination**: Coordination between different functions related to production, e.g. between maintenance and operations and between operations and the procurement of electricity
**Industrial use cases**

**(Petro-)chemical production:** Coupled processes incl. power plant and the purchase of electricity, unit switch on/off, raw materials and product grades changeovers, maintenance shutdowns scheduling

**Coordination of production and distribution of gases:** Production and distribution of basic chemical gases in an integrated site while improving energetic efficiency in the production of these gases

**Cellulose fibre production plant:** Spinbath recovery network with redundant equipment, selection and switching of resources, planning of cleaning

**Production, formulation and packaging of detergents:** Production planning and scheduling, investigation of new plant layouts

**Sterilisation and packaging of food (fish):** Batch production steps with continuous production lines, reduction of energy use in sterilisation
Expected impacts

- 10% improvement of energy and resource efficiency if implemented fully and along the value chains across all applications and sectors
- High impact on the competitiveness of all individual partners by being first using the technologies; fast followers expected after dissemination and interaction with stakeholders
- Strategic partnership between the CoPro SMEs and large industrial companies
- Long term growth in employment at the technology providing partner SMEs
- **Contribution to circular economy and industrial symbiosis**
Optimal site planning and scheduling including optimisation of plants operations and DSR

“We operate a petrochemical complex with interacting plants and produce a large number of base chemicals. We need to plan this production for at least the year ahead. With optimal planning of the site and optimisation of some of our units we can react quickly to changes in the market and save resources and energy.”

Alexander Gammersbach
Team Leader of Site Optimisation
INEOS Köln GmbH
The models in CoPro come from:

- Planning tools of INEOS in Cologne
- Data-based relations identified by TUDO
- Generic constraint formulations for discrete decisions
INEOS in Cologne use case – NH₃ network optimisation

The results were compared to historic data

• The tank levels and the load assignments for the plants are plausible
• Saving potentials in the liquefaction of NH₃

INEOS in Cologne use case – BDP modelling

- BDP = Most efficient observed operation
- An innovative approach for calculation of baselines based on statistical analysis and surrogate modelling\(^1\)
- Implemented in resource monitoring dashboards of INOES in Cologne

INEOS in Cologne use case – Optimal power plant scheduling

- Power plant of INEOS
  - Incinerates the waste gas of the production plants
  - Produces steam for the production plants
  - Electricity is produced as a by-product of producing steam pressure headers
    - Less than site demand, electricity is also purchased from the grid

- Challenge: Uncertainty of the site steam demand

- Scheduling of power plant operation under demand uncertainty
  - Two-stage stochastic optimization on a rolling horizon
“We strive to optimise the production and distribution of basic chemical gases required in the synthesis of our polymers. By means of advanced modelling, monitoring and optimisation methods, we want to improve the energetic efficiency in the production of gases while respecting environmental and safety regulations.”

Christine Maul
Team Lead of Advanced Process Control
Covestro Deutschland AG
Covestro use case – CO and H₂ network optimisation

Balancing the networks by coordinating

- Internal production
  - Considering fluctuating electricity prices
- Internal consumption
- External consumers
- Purchases from external producers
  - Minimum purchasing quantities
  - Coupled contracts with different tariffs
  - Cashback for yearly targets
- Transfer of gases between sites

Improving economics and resource efficiency by reducing waste streams and demand side response

Maxeiner et al., “Price-based coordination of interconnected systems with access to external markets,” PSE 2018, San Diego, USA
Optimal process coordination for the recovery section of EU’s largest viscose fiber production plant

“The recovery of the spinbath is the key process step in the viscose fiber production with the highest energy demand. Especially the spinbath reconcentration by evaporation requires a huge amount of heat. In CoPro our goal is to improve our multi-unit evaporation process by focusing on load allocation, cleaning cycles, cooling water distribution and the heat recovery.”

Christian Jasch
Process Engineer
Recovery & Spinbath
Lenzing AG
Viscose-fiber production process

From the pulp to the fibers

• A network of evaporation plants and plate heat exchangers form the system to reconcentrate and to reheat the diluted spinbath to required setpoints.

Challenge: High energy demand (~60% of total) of the spinbath reconcentration
Decision support tool for load allocation

Workflow:

- Fully implemented and already running in the control room.
- Reduced operator workload.
- Faster reaction against production changes.
- Up to 1.9% more efficient operation:
  \[ \approx 40 \text{ t/d steam savings} \]
  \[ \approx 250,000 \text{ \euro/y savings} \]

BONMIN gets an optimal solution in a few seconds
Optimal allocation of evaporators

**Plant surrogate data-driven model**

- Discrete variables $x_{ep}$ link product $p$ to plant $e$
- Continuous variables $EF_{ep}$ set the load in each plant
- Control setpoints for $F$ and $T$

**ACS**

**MIQP optimization**

Absolute Steam Consumption = $EF \cdot SCC$

$EF = [a_1, a_2, a_3, b_0] \cdot \begin{bmatrix} T_F \\ T_{MK} \end{bmatrix} + K_f$

$SCC = [c_1, c_2, c_3, d_0] \cdot \begin{bmatrix} F \\ T_{MK} \end{bmatrix} + K_{f_2}$

**FOULING parameters**

**RTO CONCEPT**

- Load static information
- Obtain current state
- Update fouling parameters
- Solve the MIQP optimization
- Present results to operators
The key to an efficient cleaning scheduling is the ability to monitor and predict fouling.

Proposed approach summarized:
1. **Data pre-processing stage.** Remove shut downs, unsteady operation, out-of-range points, measurement errors, corrupted data, apply data reconciliation, etc.
2. **Clean plant model building.** Select clean operating data after cleanings and generate a plant model.
3. **Fouling monitoring.** Fouling state := Difference between current data w.r.t clean model prediction.
4. **Fouling model regression.** Fit models for the fouling state w.r.t. operation time, type of spinbath, etc.
DS tool for maintenance scheduling

- Method for monitoring the fouling state of a heat exchanger developed
- Excel based DS tool for cleaning
- New cleaning sequence for a quarter of the evaporators
- Already generating savings around 30,000 €/year
Optimisation of production and packing of consumer goods products

“We produce a large number of similar products in the same plant and with the same equipment. The process of fitting all products in the daily schedule and the change from one product to the other makes it all quite complex and often not optimal. The main objective in this project is to increase the plant productivity by means of optimal planning and optimal and efficient utilisation of assets, resources and energy.”

Francesc Corominas
Principal Engineer
Procter & Gamble
P&G use case

**Challenges**
- Demand-driven production
- Great variety of products, sequence-dependent changeovers
- Plant-wide manual scheduling not possible for longer time horizons

**Benefits**
- Reduction of waste due to changeovers
- Optimised schedule translates into increased energy and resource efficiency
- Improved production capacity and flexibility
- Less work on weekends
P&G use case - Achievements

Current plant Layout:

- Two MILP-based decomposition strategies were developed
- Good quality solutions for large realistic problem instances were obtained
- All generated schedules have been fully validated by the industrial partner

Agile Layout:

- Discrete-time MILP model
- Due to the problem size a decomposition based solution strategy is applied
- Significant improvements can be achieved with the flexible layout
“At FRINSA, we produce over 400 different products on shared production equipment. Our main challenge is to optimally plan, schedule and operate the equipment to minimize queues, idle times and consumption of energy. CoPro technology will replace manual scheduling methods and will improve the energy efficiency and reduce total costs.”

Borja Mariño Pampin
FRINSA Area Manager
Frinsa del Noroeste, S.A.
FRINSA use case

- **General characteristics**
  - Large order-driven production with high production flexibility
  - **Sterilisation**: Most critical element
    - Ensures food safety & product quality
    - Energy intensive process
    - Production bottleneck

- **Main challenges**
  - Optimisation-based reactive scheduling
  - Optimisation of the sterilisation process → significant energy savings by better control and coordination with scheduling
  - Trade-offs between
    - Productivity (higher temperatures, faster sterilisation)
    - Energy consumption (lower temperatures, longer processing times)
Integrated scheduling and optimisation of the sterilisers

Operating the sterilisers at lower temperature saves energy, \( \sim 500 \text{ Kg steam} / ^\circ \text{C and batch but increases the processing time} \)

Integrated scheduling and unit optimisation for balancing of energy minimisation and throughput maximisation

The duration of a batch depends on the operating temperature

At every time instant the total steam consumed is constrained

Processing time

Steriliser optimisation provides Pareto front for complying with food safety

\[ U_1 \]
\[ U_2 \]
\[ U_m \]
\[ t_1 \]
\[ t_2 \]
\[ t_3 \]
\[ t_k \]
\[ t_{k+1} \]
\[ t_N \]
How to integrate online model based applications seamless into several levels of an heterogeneous industrial IT system environment?
CoPro Integration Framework

Solution approach: Modular Framework

- Model Integration and Interaction Control of Data Transfer to realize Real-Time Applications
- Ease of use and less engineering efforts to integrate Model Based Applications into heterogeneous IT-System Environments

Production Planning
Demand Supply Planning
Material Management
Supply Chain Management

MES
PIMS
LIMS

Detailed Scheduling
Tracking
Reporting
Forecast
Decision Support
Plant Coordination

Advanced HMI

Data Reconciliation

Big Data Analysis

COPRO - Integration Framework

Interaction Master
Real-Time Model Integration

Optimizer & Online Models
e.g. AIMMS
gPROMS
Dymola
MATLAB
ClearVu

Generic Data interfaces
OPC UA, OPC UA, SQL, ...

Generic Data interfaces
OPC DA, OPC UA, BatchML, ...

Generic Data interfaces
FMI API, OPC DA, ODBC, ...

ERP
Advanced HMI
DSP
SCM

Plant Unit 1
Plant Unit 2
Plant Unit n

Local control systems

Networks (steam, hydrogen, intermediates, ...)

Solution approach:
Modular Framework

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PSE Hybrid Modelling tool

- Hybrid models
  - Models with a “data-driven” component and a “first-principles component

- Components
  - Data-driven model estimation based on ALAMO and PLS (Partial Least Squares)
  - Prediction and quality monitoring of data-driven components in gPROMS
  - Flowsheeting library with hybrid unit operation models
  - User interface elements for surrogate modelling
  - Integrated with PSE’s gPROMS Process Modelling platform
Dynamic management for industrial symbiosis

- **Industrial symbiosis:** *Tight coupling of production units by streams of material and carriers of energy*
- Similar to Verbund-sites, but between different companies
- Available/ requested amounts of material or energy carriers depend on the operating conditions of the plants involved which are operated by different companies
- Each company has to react to customer demands, availability of green power, etc.
  → *Propagation of variability between the plants*
- **Integrated management** is needed to realise the potential of industrial symbiosis!
- Must include *sharing of benefits* in a fair manner
  - Without violating anti-trust regulations!
Distributed coordination

- Market-like distributed optimisation
  - Intuitive concept in accordance with current accounting systems
  - Scheme mimics an auction mechanism
  - Online adaptation of the prices by the coordinator (central function)
  - Research on efficient algorithms that only use the responses of the plants to the prices
  - Inclusion of external suppliers with volume-dependent prices

Wenzel et al. (2018), “Virtual Splitting of Shared Resource Networks for Price-Based Coordination with Portfolio Tariffs.” ESCAPE28, Graz, Austria
The projects leading to this application have received funding from the European Union’s Horizon 2020 research and innovation program