From unit control to optimal management of plants, sites and chemical parks

Sebastian Engell, TU Dortmund, Coordinator

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www.spire2030.eu/copro
Individual units often are already automated and operated efficiently

Inefficiencies result from lack of coordination

Better coordination of production means improved energy and resource efficiency
CoPro: Short fact sheet

- Full title: Improvement of Energy and Resource Efficiency by Better Coordination of Production in the Process Industries
- Contributing to circular economy and industrial symbiosis
- Builds on the results of FP7 projects
  - Real-Time Monitoring and Optimization of Resource Efficiency in Integrated Processing Plants
  - Dynamic Management of 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
Improved coordination is key to better energy and resource efficiency of the existing assets

CoPro addresses coordination in three dimensions:

- **Cross-layer process integration**, from basic process controls to the coordination of the complete 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
Goals

Provide and demonstrate tools for process monitoring, dynamic planning, and scheduling and control of plants, sites and industrial clusters under dynamic market conditions

- Improved energy and resource efficiency by coordinated optimization of production units
- Buffering the effects of fluctuating renewable energy production and distribution by integrating demand-side response with plant-wide scheduling and control
- Efficient plant and resource utilisation by integrated plant-wide scheduling and control
- Optimization of maintenance
| Plant and site operation efficiency largely determined by discrete events and decisions | CoPro includes discrete decisions in plant-wide control and optimisation schemes |
| Plant managers and operators have a crucial role in the operation of processing plants | CoPro develops intuitive forms of human-machine interaction and optimisation-based advanced decision support |
| Suitable mathematical models in most cases are only available for some important plant or units | CoPro develops techniques for coordination of production units that can employ models of different types |
| Operation of plants of different companies in industrial parks that are connected by energy & material streams are not coordinated | CoPro develops technology for balancing and optimising networks, and for distributing the joint benefit in industrial parks |
“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
Generation of an optimal schedule for the operation of the plants in the ammonia network
- Time horizon one month or more
- Includes logistics
- Optimization of plant loads and cold storage
- Improved resource usage
- Demand side response

Improving the coordination of strongly coupled production plants

INEOS in Cologne USE CASE – NH$_3$ network optimisation

- The optimisation model contains:
  - Mass balances
  - Operational constraints
  - Equipment limitations
  - Logistic constraints
  - Production targets
  - Negotiated deliveries

- Simulation results were obtained for a 31 days scenario

Large saving potential identified if the network operations are performed in an optimal fashion compared to recorded data

"We strive to optimize the production and distribution of basic chemical gases required in the synthesis of our polymers. By means of advanced modelling, monitoring and optimization 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
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

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
Cross-unit and cross-functional coordination of the recovery cycle in Europe’s biggest cellulose fiber plant

Objectives:
- Efficient load allocation in the multi-unit evaporator network
- Cleaning sequence coordination for the evaporator and heat recovery section
- Optimized cooling water distribution in the recovery cycle

The recovery cycle of Lenzing’s viscose fibre plant in Upper Austria
Lenzing & TUDO developed a model based decision support system for a more efficient evaporator load allocation

- Fully implemented in the control room in August 2018
- 1.8% more efficient operation
- Steam savings around 1200 t/month
- ≈ 250,000 €/year savings
- v2.0 Update with semi automatic control currently under development

HMI of the Decision Support System implemented in Lenzing control room
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 utilization 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
“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.”
**General characteristics**
- Large order-driven production with high production flexibility
- **Sterilization**: Most critical element
  - Ensures food safety & product quality
  - Energy intensive process
  - Production bottleneck

**Main challenges**
- Optimisation-based reactive scheduling
- Optimization of the sterilization process → significant energy savings by better control and coordination with scheduling

Trade-offs between
- Productivity (higher temperatures, faster sterilization)
- Energy consumption (lower temperatures, longer processing times)
Operating the sterilizers at lower temperature saves energy, ~ 500 Kg steam /°C and batch but increases the processing time.

Integrated scheduling and unit optimization for balancing of energy minimization and throughput maximization.

The duration of a batch depends on the operating temperature.

Sterilizer optimization provides Pareto front for complying with food safety.

At every time instant the total steam consumed is constrained.

Processing time

Energy

T

time
Hurdles for solving such integrated optimisation problems
- Missing information
- Complexity of the problem
- Scalability and adaptation to changes
- Heterogeneous modelling approaches
- Agility
- Confidentiality of information

Finding the system-wide optimum by centralized optimization is often not practically implementable.
Outlook – Distributed coordination

Solution approach:

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)
- Only limited data exchange between the subsystems required (resource production/consumption)

Wenzel et al. (2018). “Virtual Splitting of Shared Resource Networks for Price-Based Coordination with Portfolio Tariffs.” ESCAPE28, Graz, Austria
CoPro Technologies and tools

- **Plant-wide and site-wide optimisation** of operating points and discrete decisions including demand side response
- **Distributed optimization using market-like algorithms** to coordinate with minimum exchange of information
- **Technology for optimising changeovers**, reducing waste, rework and energy consumption and increasing throughput
- **Reactive scheduling** to maximize utilisation of the equipment and to minimize energy consumption
CoPro  Technologies and tools

- **Online data analytics** for the detection of quality and equipment problems from available sensor information
- **New modelling techniques** to build models for advanced control and plant-wide optimisation efficiently
- **Novel forms of information presentation** to managers and operators that lead to a symbiosis of operators and computer-based optimization algorithms
- **Software platform** that connects to different IT systems and to visualization systems and facilitates the engineering and maintenance of integrated control and optimisation solutions
Expected impact

- 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 technology providing partner SMEs
- **Contribution to circular economy and industrial symbiosis**
Outlook: 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 realize the potential of industrial symbiosis!
- Must include *sharing of benefits* in a fair manner
  - Without violating anti-trust regulations!
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- ResearchGate:
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Matti Vilkko
Tampere University of Technology
Coordinating Optimisation of Complex Industrial Processes
Matti Vilkko

Towards Industry 4.0: Digital Technologies in Process Industry
1.10.2018
Outline

- COCOP intro
  - Pilot cases: Copper, Steel
- Optimisation and decomposition
  - Plant-wide approach
- Communication architecture
- COCOP Concept
  - Integration of optimisation, communication technologies and human factors
Consortium

- 12 partners
  - 5 research organisations and
  - 7 companies, 4 of which are SMEs
- Copper, steel, nutritional and materials products, automation technology providers, consultancy and software

Universities

Technological Research Centers

SMEs

Large companies
Pilot Cases

• On-site application and validation at two plants

STEEL pilot case
➢ Development of a steel manufacturing plant-wide monitoring and control tool in order to reduce the surface and sub-surface defects in micro-alloyed steels in as-rolled state
➢ Addressed sub-processes: Secondary metallurgy, continuous casting and hot rolling

COPPER pilot case
➢ Development of advisory tools for controlling unit processes to improve factors such as temperature, slag chemistry and impurities
➢ The optimization will comprise of converter and anode-furnace scheduling & setting target matte grades and feed rates of flash-smelting furnaces

• Transferability analysis to other sectors: chemical & water treatment processing

COCOP – Coordinating Optimisation of Complex Industrial Processes, 1.10.2018, Matti Vilkko
Copper smelter

COCOP – Coordinating Optimisation of Complex Industrial Processes, 1.10.2018, Matti Vilkko
Copper smelter control rooms

Flow sheet copper production

COCOP – Coordinating Optimisation of Complex Industrial Processes, 1.10.2018, Matti Vilkko
Motivation and Objectives

**Vision**
Complex process industry plants will be optimally run by the operators with the guidance of a coordinating, real-time optimisation system.

**Objectives**
To enable plant-wide monitoring and control by using the model-based, predictive, coordinating optimisation concept in integration with local control systems.
Optimisation architecture: decomposition and coordination
Information models and communication in COCOP
COCOP communication based on a message bus
Conclusion – Convergence of Internet based approach and traditional process automation

Upcoming Workshop

DIGITIZED OPERATIONS for SUSTAINABLE PROCESS INDUSTRIES

DECHHEMA - Frankfurt am Main, Germany

18 October 2018, 9:30 – 20:00

Participation of A.SPIRE, EFFRA and EC DG Research and Innovation

FREE ATTENDANCE REGISTRATION REQUIRED!!
General details

• Project Start Date: 1\textsuperscript{st} October 2016
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• Grant Agreement n.: 723661
• Sub-programme area: SPIRE-02-2016, H2020-IND-CE-2016-17
• Web page: \url{www.cocop-spire.eu}
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Thank you for your attention!

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MONSOON project:
Boosting the development and deployment of data enabled predictive control solutions for process industries

Claudio Pastrone, ISMB

Towards Industry 4.0: Digital Technologies in Process Industry
Bruxelles, October 1st, 2018
Outline

• Project Overview
• MONSOON Vision
• Use Cases
• First Achievements
PROJECT OVERVIEW
INTRODUCTION TO MONSOON
Context and main challenges

• Process industries characterized by intense use of raw resources and energy, where even small optimizations can lead to high absolute savings both in terms of economic and environmental costs

• Deployment of model-based predictive functions not always feasible at a sustainable cost or with sufficient reliability

• Change in global competition and resources availability calls for a drastic re-design of production processes and sites
MONSOON at a glance

- **MONSOON** is a 36-months Research and Innovation Action (RIA) funded by the EC (H2020 SPIRE-02-2016)

- **Scope**: Plant-wide monitoring and control of data-intensive processes

- **Aim**: improve process efficiency and reduce usage of resources as well as GHG emissions, thus strengthening the global position of EU process industry

- **Total cost**: about 5.5 M€
Consortium Overview

11 partners from 7 EU Countries
MONSOON Objectives

To provide replicable and cost-effective data-driven methodology and tools to support identification and exploitation of optimization potentials by applying model based predictive control solutions.

To provide an integrated ICT/IoT infrastructure enabling the virtualization of heterogeneous monitoring and control systems into digital twins.

Application of Data Analysis and Visualization techniques exploiting high amounts of production data to support predictive control and plant and site wide optimization.
A novel model based development environment – Cross-Sectorial Data Lab – to facilitate design, development, integration, deployment and testing of predictive control algorithms

Symmetric plant and site-wide Online Life Cycle Management Tools (also entailing circularity aspects) integrated with the monitoring and control infrastructure

Demonstration and Evaluation of the proposed solution in the Aluminium and Plastic Industry
MONSOON enabled Vision

MONSOON Data Lab
Cross-sectorial collaboration to develop data-driven Model Based Predictive Functions

Orient
Dynamic Multi Scale Cross-sectorial Process Industry Models

Observe
Impact Evaluation, LC Assessment

Act
Multi Scale Distributed Controls Runtime in the Factory

Decide
Impact prediction, Feasibility Assessment

Rapid Prototyping and Deployment of Model Based Predictive Functions

Hybrid off-line and on-line evaluation of model based Predictive Functions (development, iterative fine-tuning, etc.)

Scalable Real-time Monitoring of Data-Intensive Processes from Multiple Production Sites

Cross-sectorial Use Cases
- LC Management
- Process Management
- Simulation
- Training
- Operational Conditions Management

Cross-sectorial Use Cases

MONSOON enabled Vision

Digital Technologies in Process Industry

Brussels, 01-10-2018
MONSOON Application Domains

Aluminium
Primary Production

Dunkerque plant (FR)
Highest-producing primary aluminium plant in the EU-28 area (consumption 3.7 TWh of electricity - equivalent to a 1 million people city)

Plastics
Injection moulding

Maceira-Leiria plant (PT) – GLN
Injection moulding machines
ALUMINIUM USE CASE
• **Prediction of Anode Quality**
  – *detect bad anodes* with high level of confidence and avoid forwarding them to the electrolysis area
  – *predict* non conformant production (global or individual anomalies) and *trigger* relevant actions to correct the problem

*Anode non-quality can lead to non-homogeneous and reactive anodes*

- **Dusting in pots**
- **Reduced lifecycle on pots** (more frequent anode change)
- **Incidents on pots** like mushrooms (spikes), flatness defect (deformation)
- **CO₂ emissions** due to the anode overconsumption
Green Anode Production

- **Predictive Maintenance**
  - Prediction of paste plant stoppages and equipment deviation
  - Identification of correlation between equipment deviations and stoppages and decrease of anode quality to trigger relevant actions and predictive maintenance operations

  Monitoring of equipment most impacting on anode production
  - **Paste mixer**: machine to prepare the paste
  - **Paste cooler**: machine to cool down the paste before the forming step

  Results could be used as a basis for the predictive quality enhancements
Electrolysis Area

- Predict in real-time the liquid heights (bath and metal)
- Predict in real-time the thermal balance

These two variables have a great impact on the pot performances that are the optimized energy consumption and current efficiency.

Objectives:
- Give indications on the appropriate operations to be done on the pot (adjustments of the bath volume, volume of metal to be tapped...)
- Give optimal parameter settings based on process expertise
- Anticipate process deviations via predictive alerts and take countermeasures (e.g. adjust parameters settings) to improve pot stability.
PLASTIC USE CASE
**Injection Moulding – Coffee capsules**

- **Polypropylene coffee cups and respective lid - being produced**
  - in large quantities (400,000 units produced per machine/day)
  - with a fixed product flow and small variations
  - with a high production rate
  - using 32 cavity moulds, 6.5 – 7 sec cycle
Injection Moulding

• Objectives
  – to reduce production stoppages and
  – decrease the waste of raw material (mainly caused by height deviation from nominal values in produced capsules)

• Considered steps
  – Exploit the data coming from the injection moulding machines, possible additional sensors and from the inspection system (properly updated to collect information useful for predictions)
  – predict equipment/process deviations that impact the quality of manufactured capsules
  – predict capsules quality as binary classification (high/low quality)
  – trigger relevant actions to correct the problems
FIRST ACHIEVEMENTS
**Ramp up phase**

***Data driven approach***

- MONSOON **Data Collection** and **Monitoring infrastructure** installed in real environment, also supporting interoperability between heterogeneous plant systems, sensors and actuators.
- Initial **Cross Sectorial Data Lab** – big data storage and analytics platform and GUIs presenting observed data.
Cross Sectorial Data Lab

- First release of the Big Data Storage and Analytics Platform, adopting and extending open source solutions
  - KairosDB (time series query engine), Cassandra (distributed database) and Grafana
  - Python tools for data analytics (SciKit learn, Xgboost, LIME, …)
  - Apache Zeppelin – collaborative development environment customized and extended for Docker environment, i.e. scripts edited in Zeppelin are running in Docker container connected to Big Data storage

- Semantic Framework to simplify communication between the domain experts and data scientists across different domains.

Brussels, 01-10-2018
Online and deep machine learning solutions

Anode quality
- A machine learning model classifies 30 minutes periods of anode production as high or low quality, using only process data (51 variables)
- Identification (with the help of process experts) of possible new causes of abnormal anode quality and relevant actions to correct/mitigate the issues

The model has been deployed and connected to real data flow

Anomalies in the paste plant
- Unsupervised machine learning techniques (clustering) have been used to identify the different behaviours of the paste plant equipment
- Preliminary analysis for BUSS mixer proved to be valuable

Insights about several BUSS mixer behaviours
Enabling easier and faster deployment to the field

- **Runtime Container** – ICT infrastructure *(based on Docker technology)* supporting more easily and quickly deployment to the real environment of **predictive control functions** and LifeCycle (LC) calculations designed, developed and tested in the Cross-Sectorial Data Lab (MONSOON model based development environment)

  - **Executes** at runtime model based predictive control functions and LC online calculations
  - Ensures proper deployment, execution and **access** to relevant **industry resources, data** from sensors, actuators and sub-systems
  - **Manages** the **life cycle** of predictive control functions and LC online calculations
  - Provides **data visualization solutions** and **dashboards** embedded on the Plant Platform, also displaying predictive alerts
additional results are still to come!!

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-presented by-

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Upcoming Workshop

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