A Discrete-Time Scheduling Model for Continuous Power-intensive Process Networks with Various Electricity Contracts

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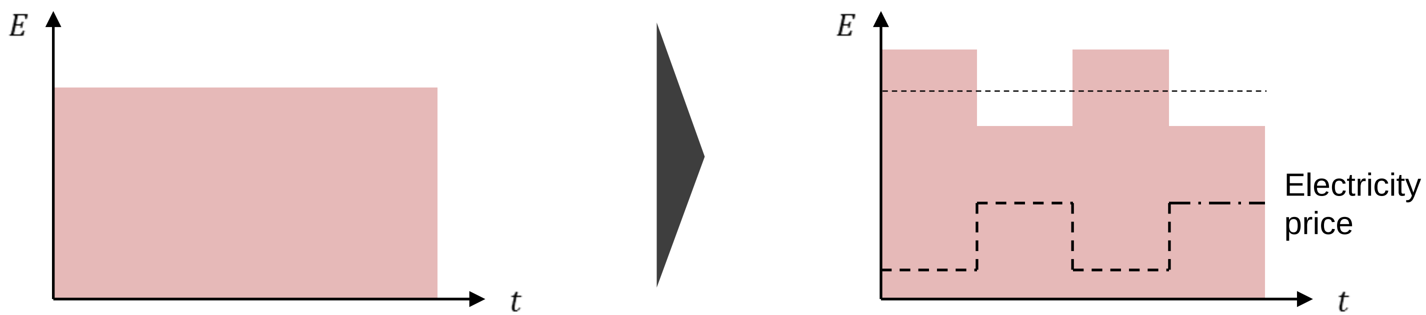
Enterprise-wide Optimization Meeting
Pittsburgh, September 2014

In the era of Smart Grid, efficient scheduling models for industrial power-intensive processes are crucial.

- In the context of Demand Side Management, industrial power-intensive processes can achieve large benefits by optimizing their power consumption
- The plant's flexibility can be used to shift load depending on the time-sensitive prices and the conditions of the electricity contracts



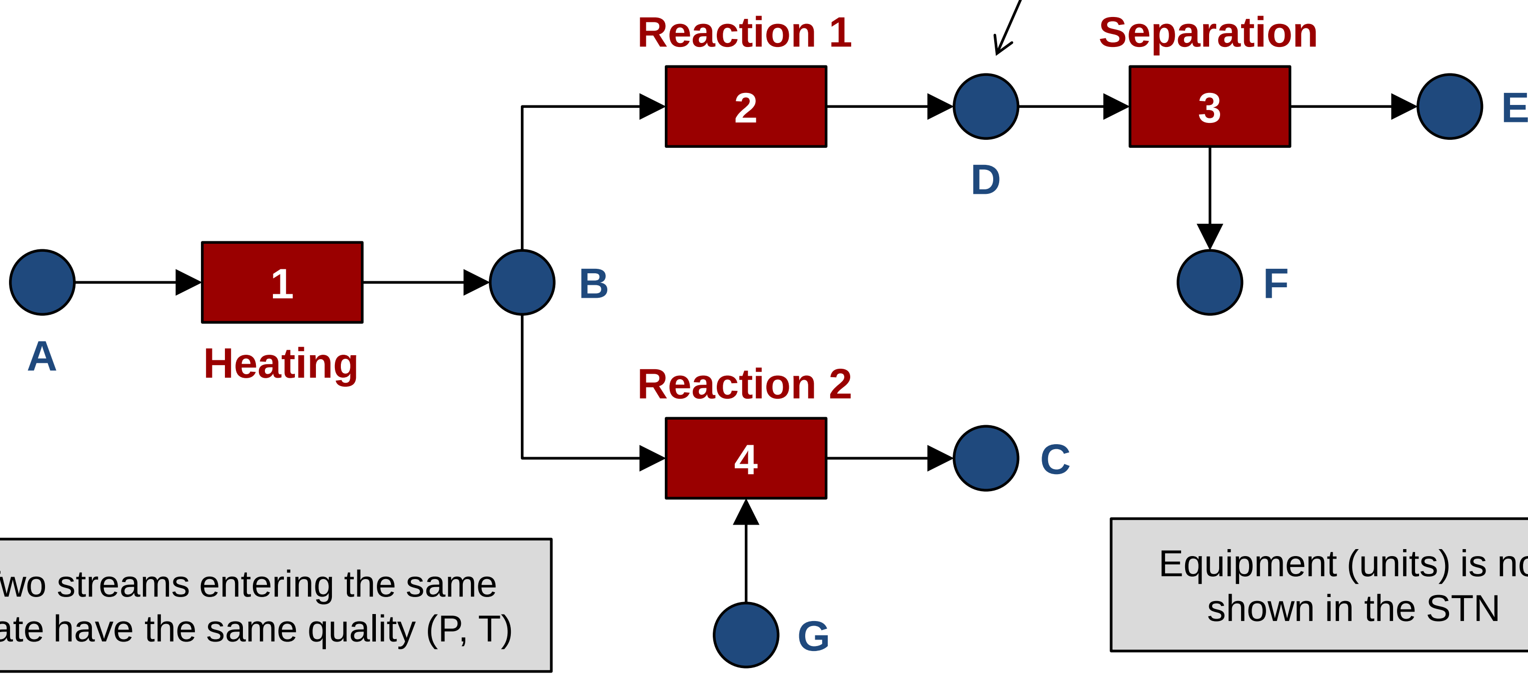
Constant operation | Load shifting

We develop a discrete-time scheduling model for general continuous power-intensive process networks considering various electricity contracts.

To model the process network, we apply the concept of the state-task network (STN).

- **Two types of nodes:**
  - State nodes: feeds, intermediates, products
  - Task nodes: processing steps

Storage = accumulation of material in states

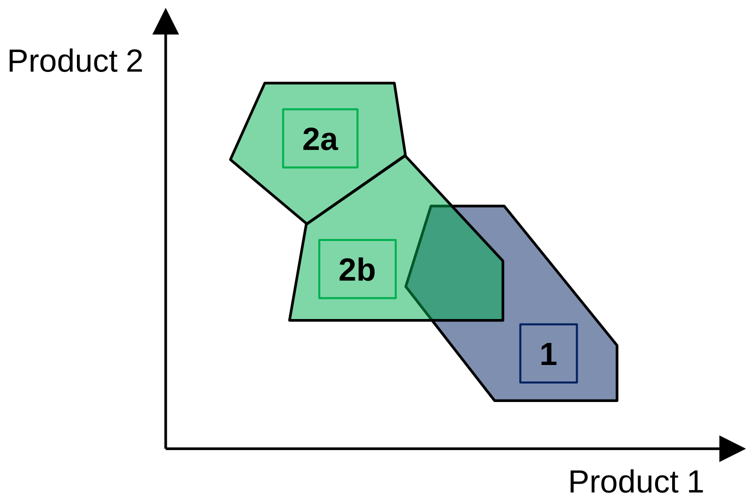


Two streams entering the same state have the same quality (P, T)

Equipment (units) is not shown in the STN

Each equipment unit is modeled as a set of Convex Region Surrogate (CRS) models.

- Assume that a piece of equipment can run in different operating modes
- The feasible region of each operating mode is expressed as a union of convex regions in the state space
- For each region, the required power consumption is a linear function of the states
- Can be stated as a nested disjunction, which can be reformulated as a set of MILP constraints[1]



$$\bigvee_{m\in M_{ij}} \left[\begin{array}{c} Y_{ijmt} \\ \bigvee_{r\in R_{ijm}} \left(\begin{array}{c} \overline{Y}_{ijmrt} \\ P_{ijst} = \sum_{l\in L_{ijmr}} \lambda_{ijmrlt}\, \phi_{ijmrls} \quad \forall s\in S_i \\ \sum_{l\in L_{ijmr}} \lambda_{ijmrlt} = 1 \\ 0 \le \lambda_{ijmrlt} \le 1 \quad \forall l \in L_{ijmr} \\ U_{ijt} = \delta_{ijmr} + \sum_{s\in S_i} \gamma_{ijmrs} P_{ijst} \end{array} \right) \end{array} \right] \quad \forall i,\, j\in J_i,\, t\in \overline{T}$$

$$\underline{\bigvee}_{m\in M_{ij}} Y_{ijmt} \quad \forall i,\, j\in J_i,\, t\in \overline{T}$$

$$Y_{ijmt} \Leftrightarrow \underline{\bigvee}_{r\in R_{ijm}} \overline{Y}_{ijmrt} \quad \forall i,\, j\in J_i,\, m\in M_{ij},\, t\in \overline{T}$$

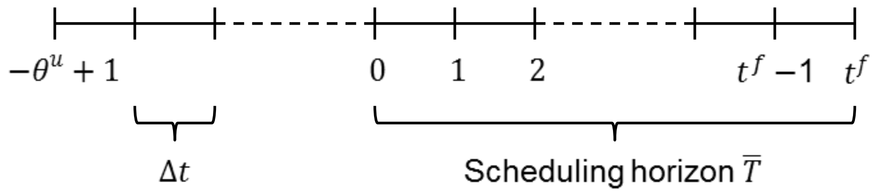
$$Y_{ijmt} \in \{true,\, false\} \quad \forall i,\, j\in J_i,\, m\in M_{ij},\, t\in \overline{T}$$

$$\overline{Y}_{ijmrt} \in \{true,\, false\} \quad \forall i,\, j\in J_i,\, m\in M_{ij},\, r\in R_{ijm},\, t\in \overline{T}$$

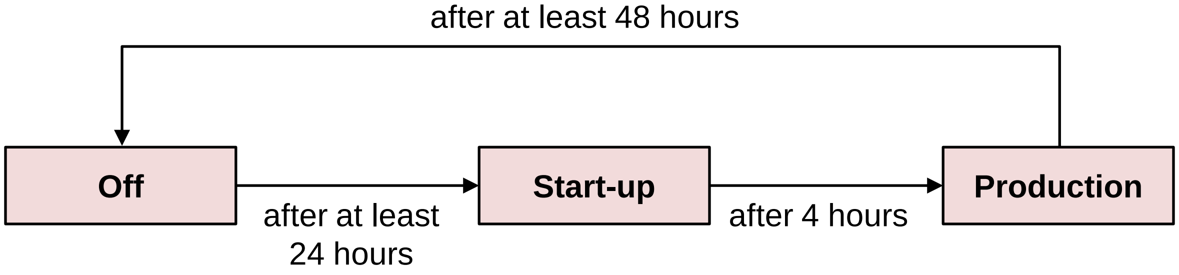
1. Grossmann and Trespalacios (2013). *AIChE Journal.*

We apply a discrete-time formulation to model transitions between operating modes[1].

- The time horizon is divided into time periods of equal length (typically one hour)



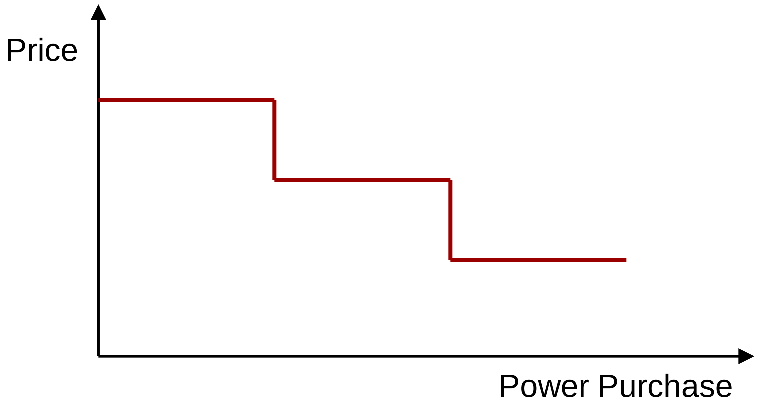
- For every time period, operating mode and production rates are determined
- Constraints on mode transitions can be imposed



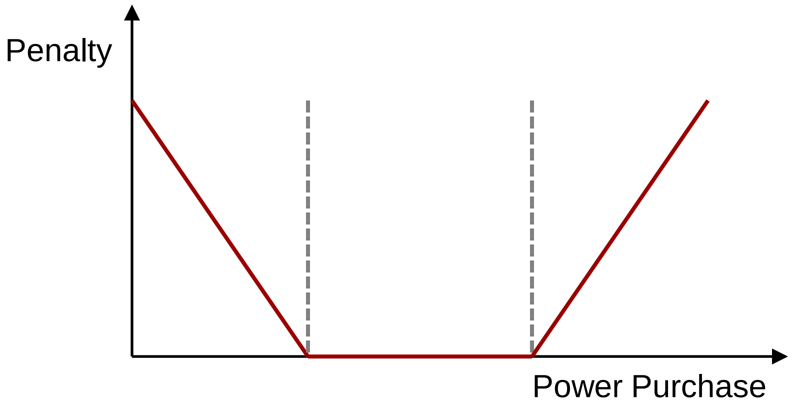
1. Mitra et al. (2012). *Computers and Chemical Engineering.*

A large variety of electricity contracts can be modeled by using a block contract formulation.

- Assigns prices to every time period
- Tracks cumulative power purchases for predefined meter reading times
- Can accommodate discount prices that depend on the amount of power purchased
- Can accommodate penalties for under- and overconsumption

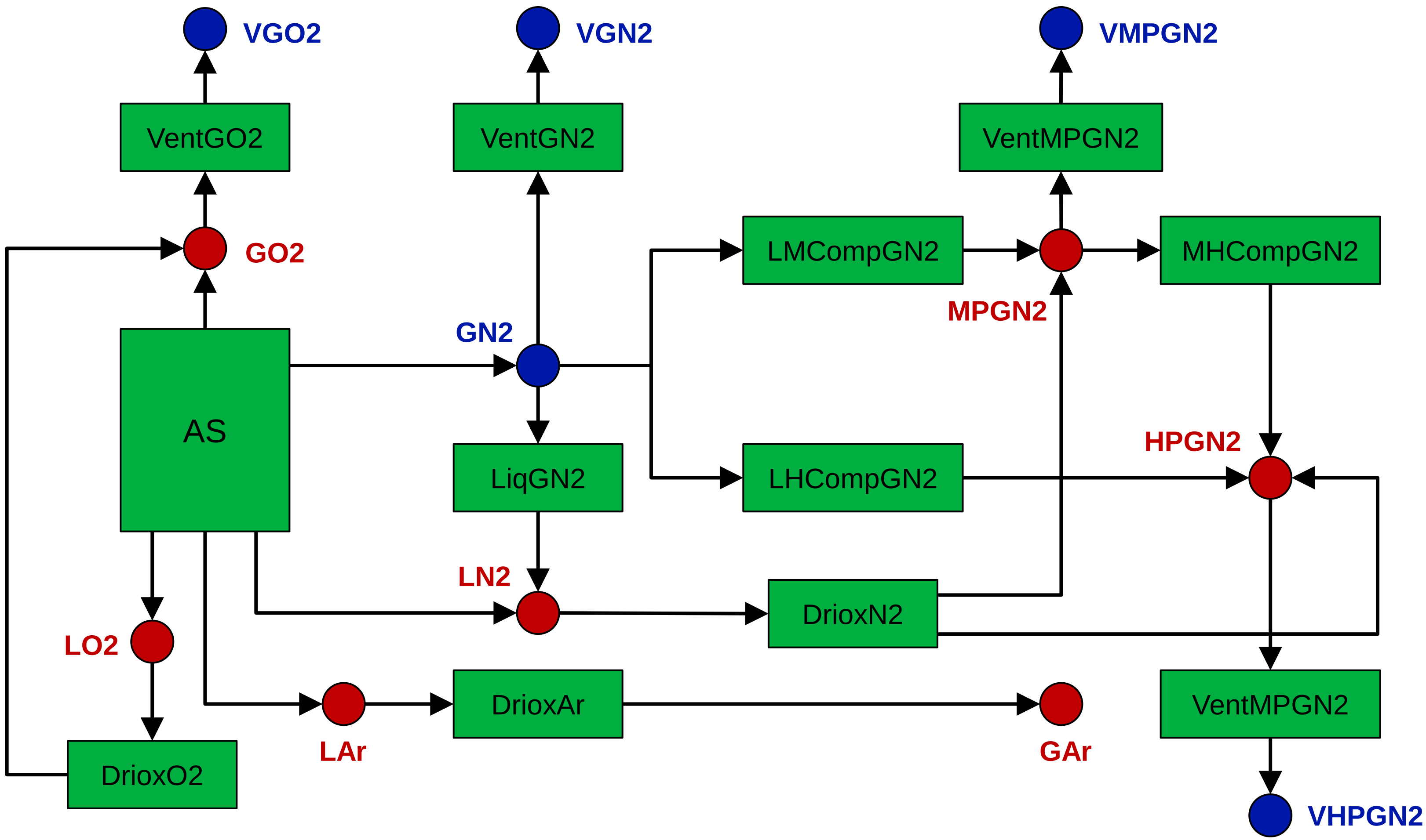


Discount Contract



Penalty Contract

Air Separation Case Study: State-Task Network



Air Separation Case Study: Results