Hierarchical Production Scheduling in the Process Industry

MARKET-DRIVEN SYSTEMS, APRIL 15, 2016
ANNA LINDHOLM

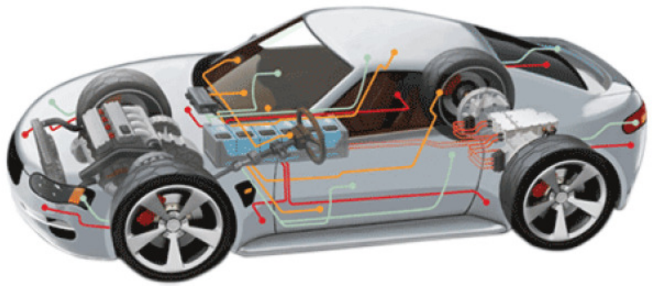
About me

- PhD in Automatic Control, Lund University
- Defended my PhD thesis *“Hierarchical Scheduling and Utility Disturbance Management in the Process Industry”* in October 2013
- Research within process industrial centre, collaboration with Perstorp
- Worked at ÅF 2014-2015
- Work at Modelon in Lund since October 2015

Modelon


MODELON MISSION
Improve customer output from their engineering effort with relevant and efficient deployment of model-based systems engineering, by:
- developing and offering open standard solutions and platforms for next generation analytical model-based systems engineering
- in particular: 100% commitment to Modelica and FMI

Modelica and FMI



- Modelica
  - Object-oriented modeling language
  - Acausal and equation based
  - Supports multi-domain modeling
  - Owned by the Modelica Association (non-profit organization)
- FMI – Functional Mock-up interface – is a standardized way for models from different tools to interact
  - Allows for export and import of models to and/or from simulation environments that does not support Modelica, e.g.
    - » Excel
    - » Matlab/Simulink
    - » ADAMS, Simpack, CarMaker
  - Sister technology to Modelica
  - Maintained by Modelica Association

Modelon

Modelon Solution Strategy

Deploy open standards for versatile tool-chain architecture

- Engineering Services - to provide tailored solutions

  Model-based systems engineering, industry solutions, physical domains, tool-chain integration, modelling, simulation and optimization

- Software Solution Sales - to provide best of breed tools

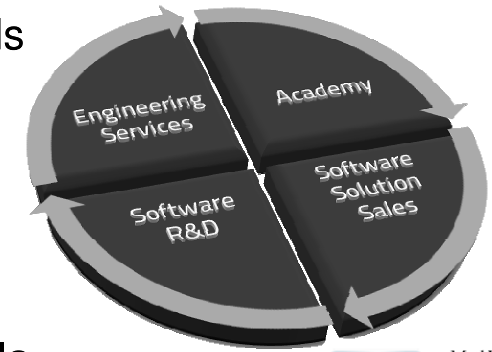
  Partner tools, Modelica libraries, Modelica and FMI tools

- Software R&D – to complete the toolchain

  Modelica libraries, FMI and Modelica tools

- Training - to ensure customer productivity

  Modelica and FMI, Modelica libraries, Modelling, Dymola



Modelon Team

~70 Engineers (MSc / PhD levels)

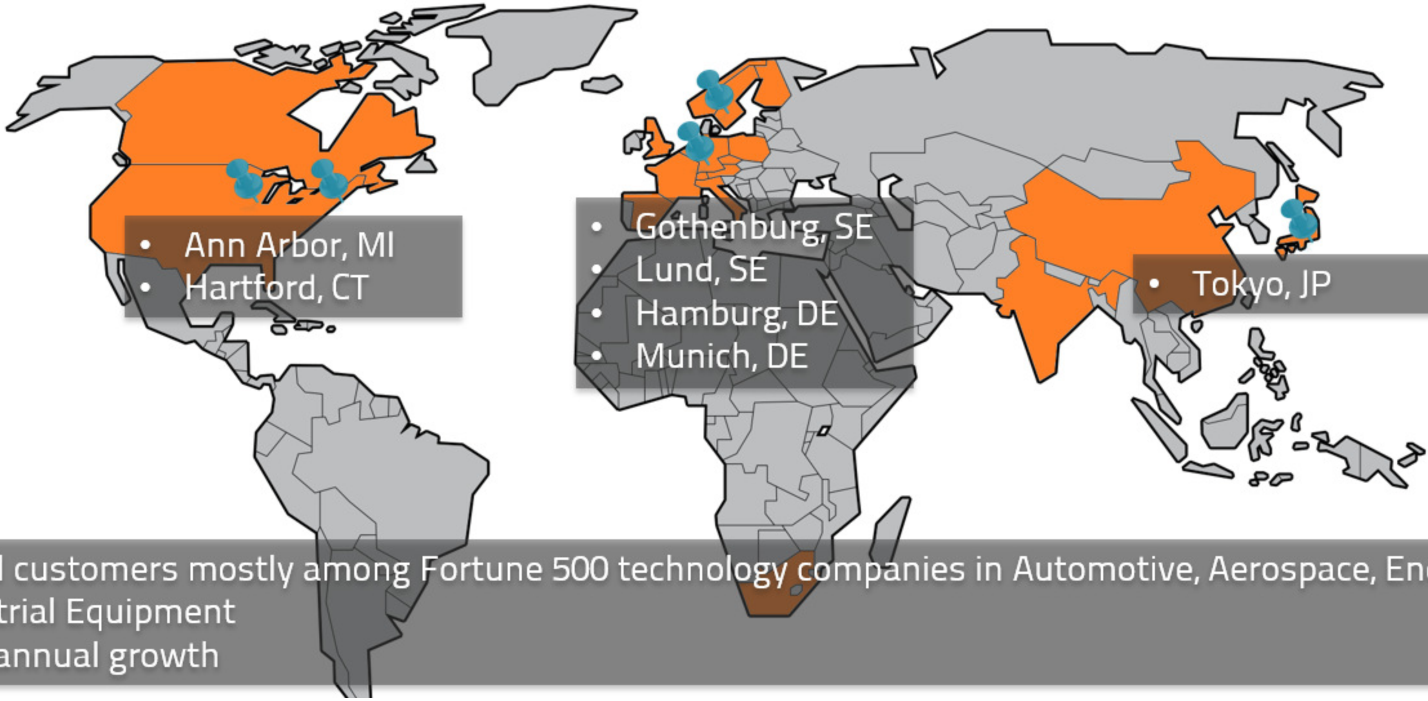
Analytical model-based engineering center of excellence

Dedicated to Modelica and FMI open standards

Expert knowledge in

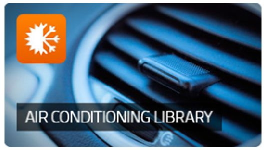
- a wide range of technical domains
- related physics and mathematics
- software design

Customer and Office Locations



- Global customers mostly among Fortune 500 technology companies in Automotive, Aerospace, Energy and Industrial Equipment
- >30% annual growth

Modelon Modelica Libraries



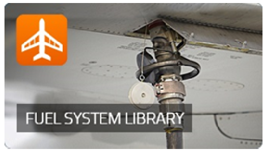
Air Conditioning Library is deployed by OEMs and system suppliers in the automotive or aerospace industry. It features a broad set of available media.

Electric Power Library covers AC three phase, AC one phase and DC systems. Handles steady state and fast transient simulation and initializaticn using dq transform.

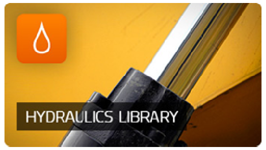
Engine Dynamics Library is used to study pressure and thermal dynamics of the complete air gas exchange process, both offline and in HIL applications.

Environmental Control Library is designed to study energy consumption and thermal conditions that affect the level of comfort for passengers and crew.

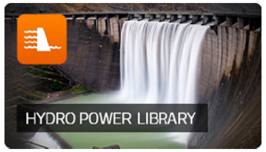
Fuel Cell Library targets modeling, simulation, analysis and control fuel cell design, especially for PEMFC and SOFC systems.



Fuel System Library targets the design and verification of fuel systems on civil and military aircraft during various dynamic operating modes and flight conditions.

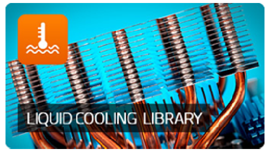


Hydraulics Library is used to design hydraulic components and systems. Applications include machine tools, transmissions, aerospace and actuation systems.

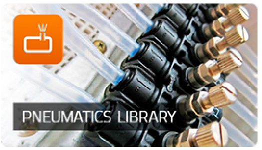


Hydro Power Library is designed for commissioning, testing of new control strategies as well as development and verification of new hydro power plant designs.

Heat Exchanger Library is used for heat exchanger design including dimensioning and stacking. Models account for inhomogeneous air flow and temperature distribution.



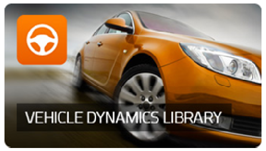
Liquid Cooling Library is used for system design with compressible or incompressible flow. Applications include engine cooling & thermal management, machines cooling.



Pneumatics Library is used to design pneumatic components and systems. The application focus is low pressure actuation systems in a variety of industries.

Thermal Power Library covers the complete steam cycle and the flue gas side. Applications covers industrial boilers, combined cycle, coal fired and nuclear power plants.

Vapor Cycle Library covers both heating, cooling and cryogenic applications. Used for automotive, aerospace and residential cooling and heating applications, and industrial refrigeration



Vehicle Dynamics Library provides architecture and contents for full vehicle dynamics. Applications cover optimization, offline simulation, driver simulators and HIL.

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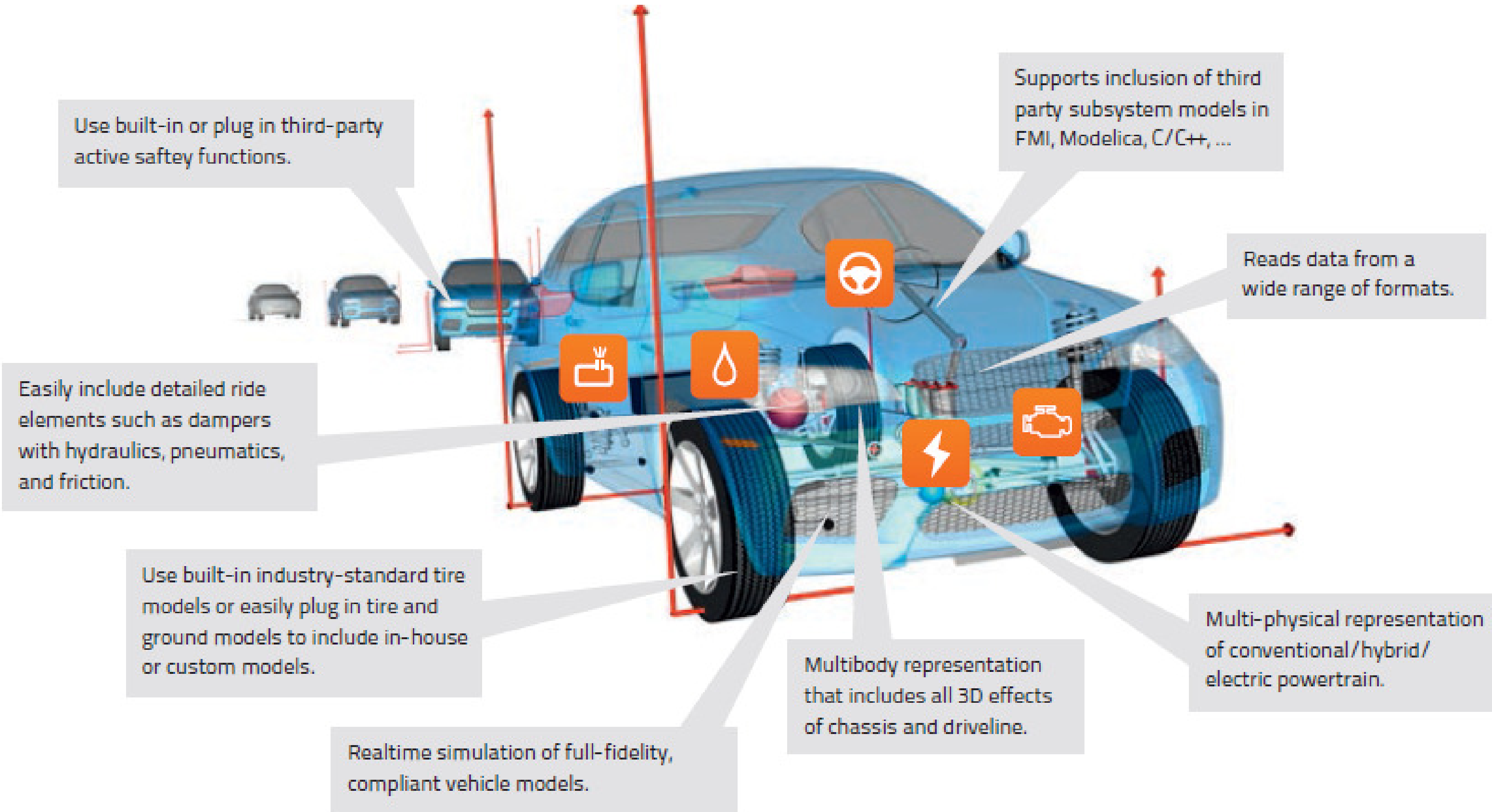
Modelon Solutions



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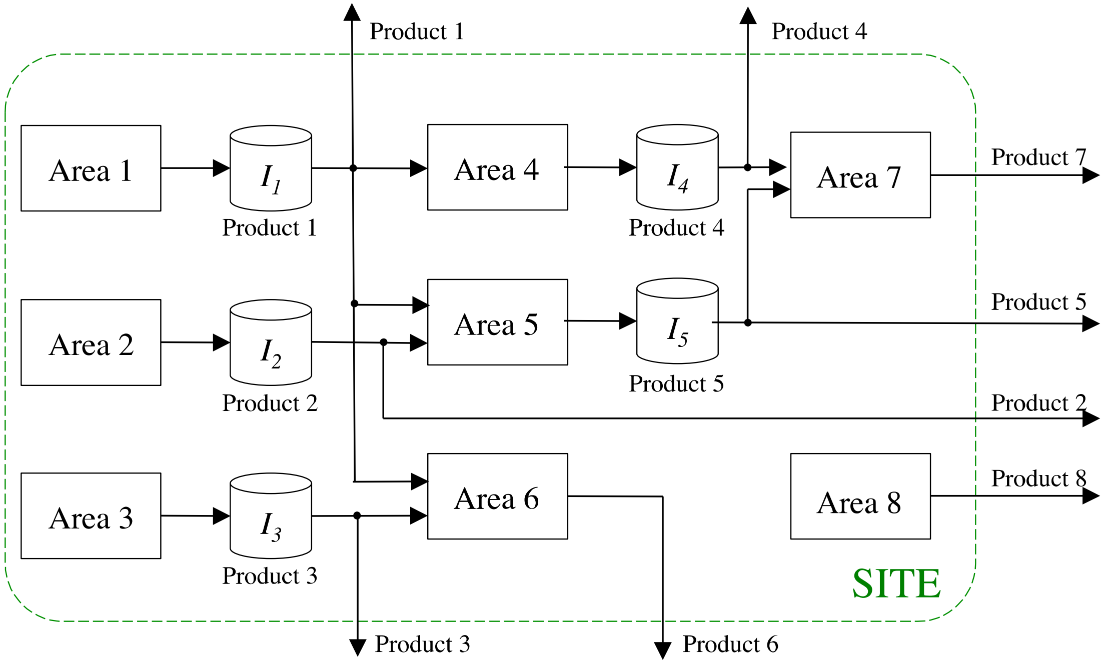
Hierarchical Production Scheduling in the Process Industry

Hierarchical Production Scheduling in the Process Industry

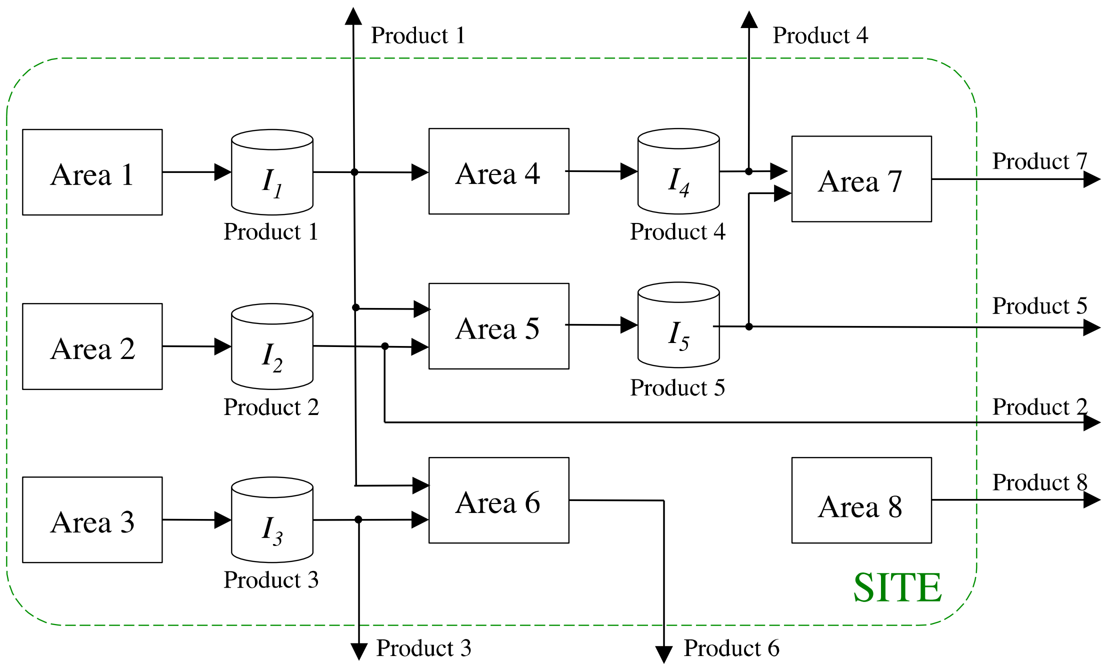


Utilities in the process industry

Utilities are support processes that are utilized in production, but that are not part of the final product."

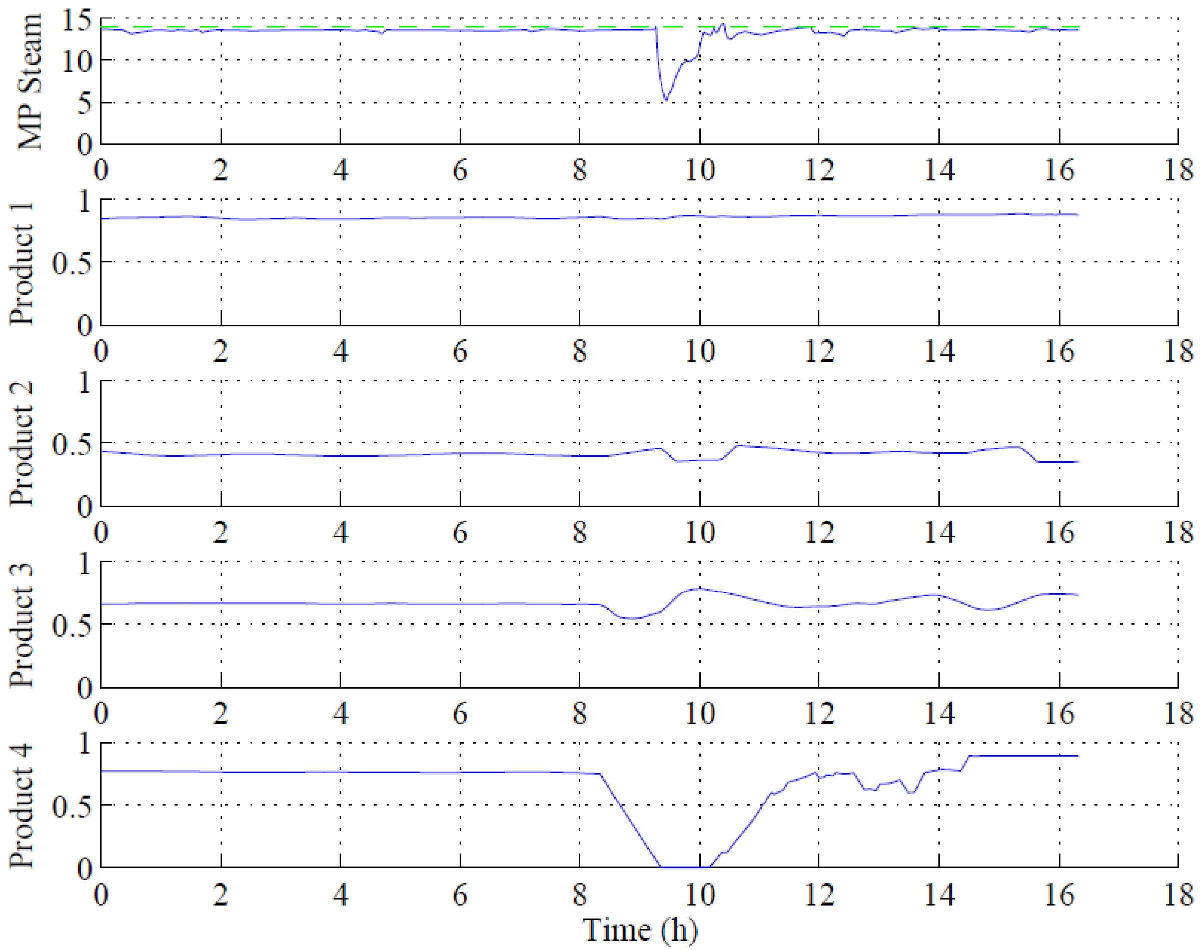
- Steam
- Cooling water
- Electricity
- Fuel
- Water treatment
- Combustion of tail gas
- Nitrogen
- Water
- Compressed air
- Vacuum system

Hierarchical Production Scheduling in the Process Industry



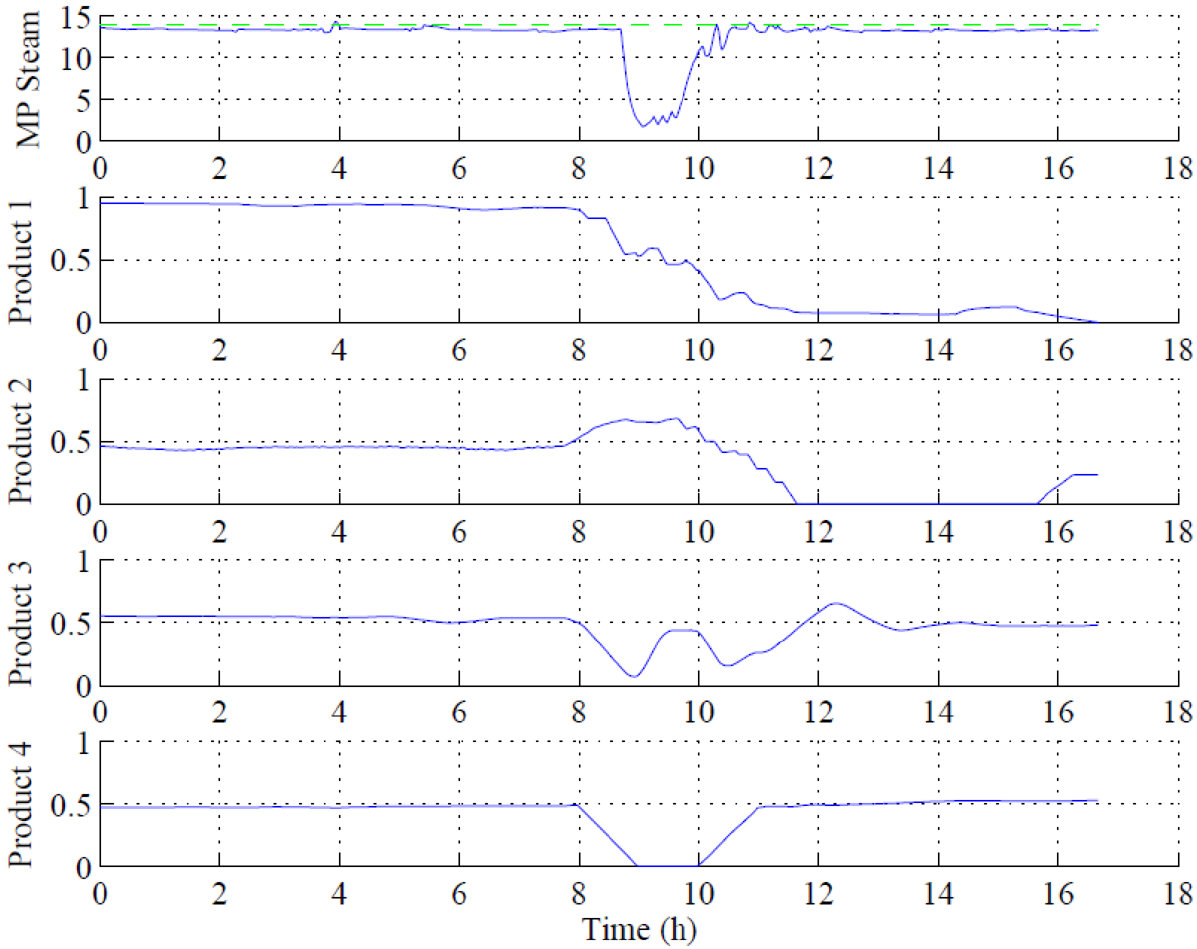
An industrial example (1)

Example 1: Pressure drop in middle-pressure steam net



An industrial example (2)

Example 2: Pressure drop in middle-pressure steam net



How can we minimize losses due to utility disturbances?

- **Proactive disturbance management**
  Disturbance management strategies that are aiming to prevent future disturbance occurrences
  - choice of inventory levels
  - choice of focus for maintenance efforts

- **Reactive disturbance management**
  Disturbance management strategies for handling disturbances when they occur
  - decision support for how to control the production
  - automatic control

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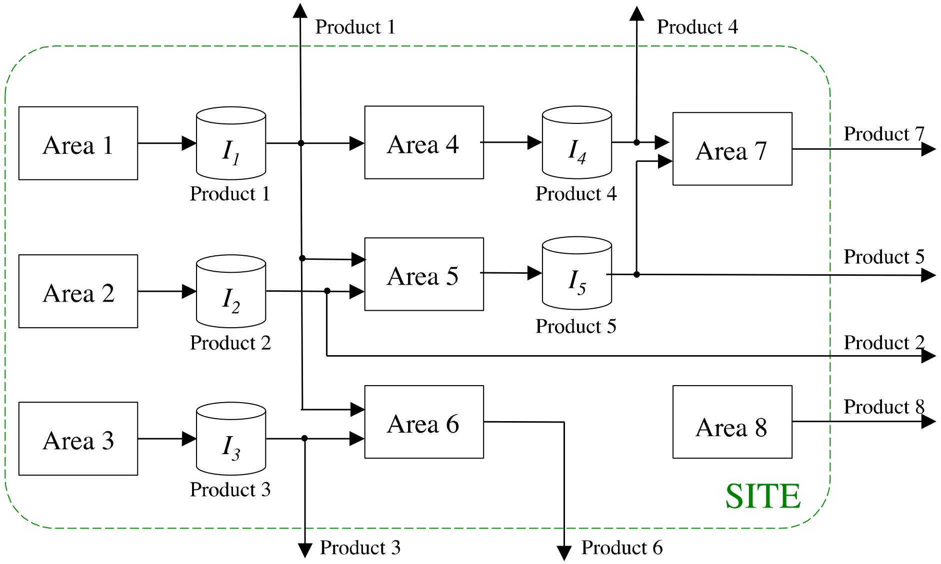
Reactive disturbance management



- How should a site be operated in order to minimize the economical effects of disturbances in production?
- How can we integrate production scheduling at different levels of the functional hierarchy of a site?

Use knowledge from both production economics, optimization and automatic control.

Develop a general method, that may be used by several different process industrial companies.

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PIC-opic project

Optimization Performance Integration Control

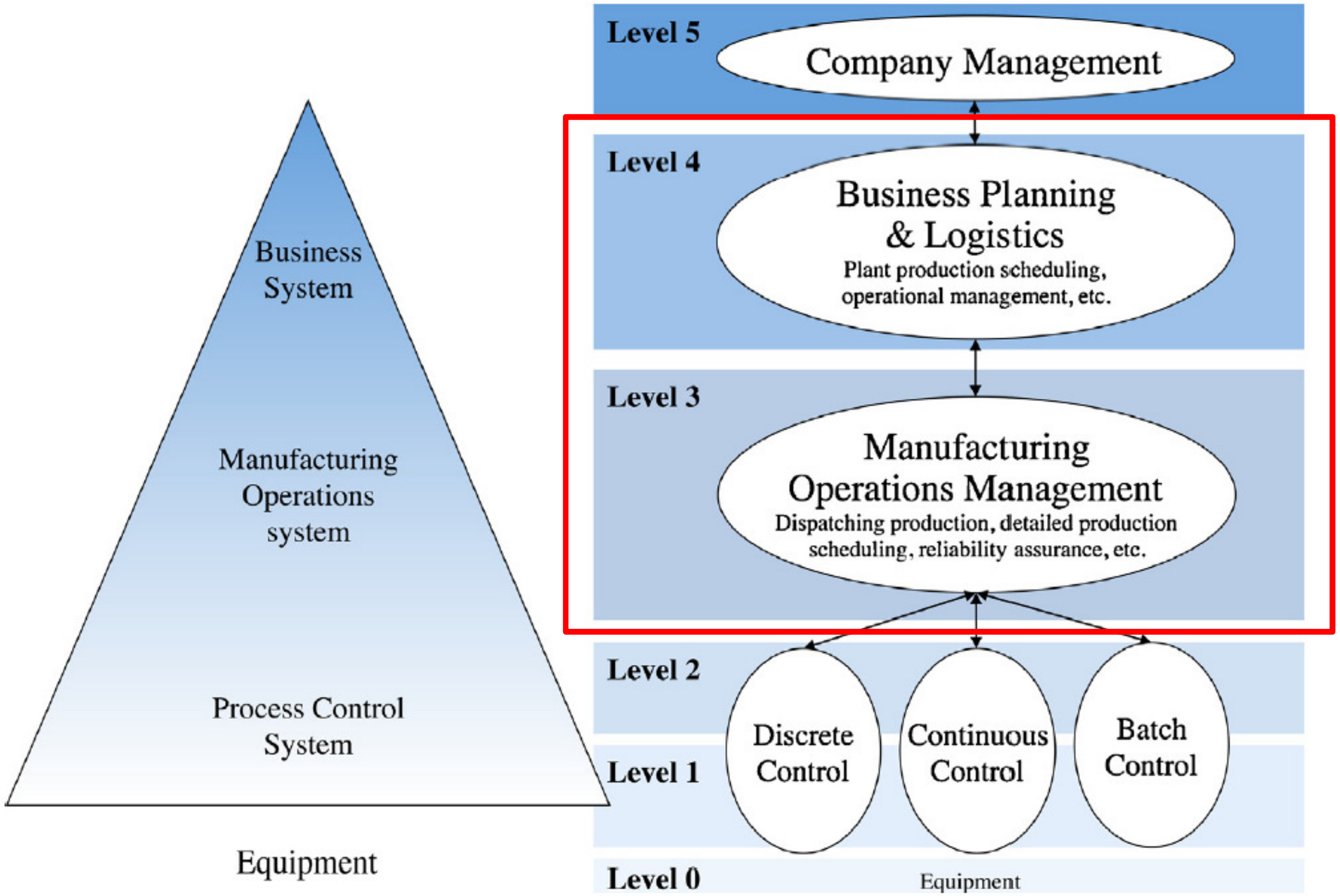
- *Department of Automatic Control, Lund University*:
  Anna Lindholm, Pontus Giselsson, Charlotta Johnsson

- *Department of Mathematics, Linköping University*:
  Nils-Hassan Quttineh

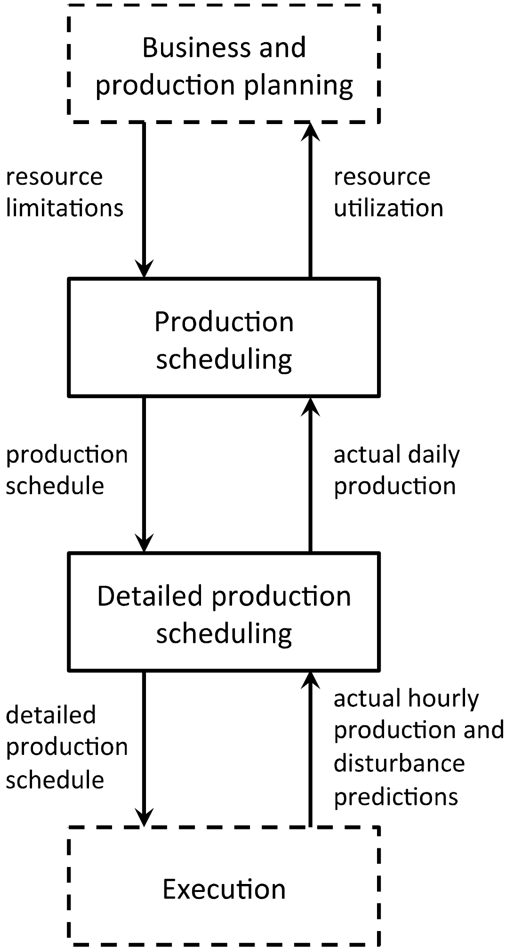
- *Department of Management and Engineering, Linköping University*:
  Helene Lidestam, Joakim Wikner, Mathias Henningsson

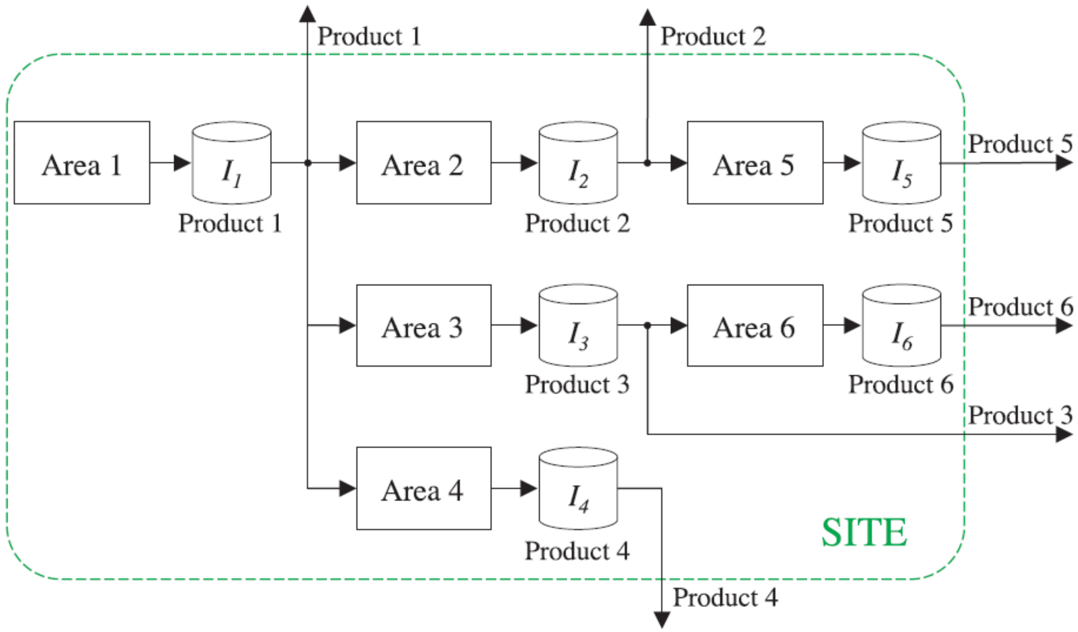
- *Perstorp*: Krister Forsman, Nils-Petter Nytzén

ISA-95 Functional Hierarchy



Hierarchical structure for scheduling





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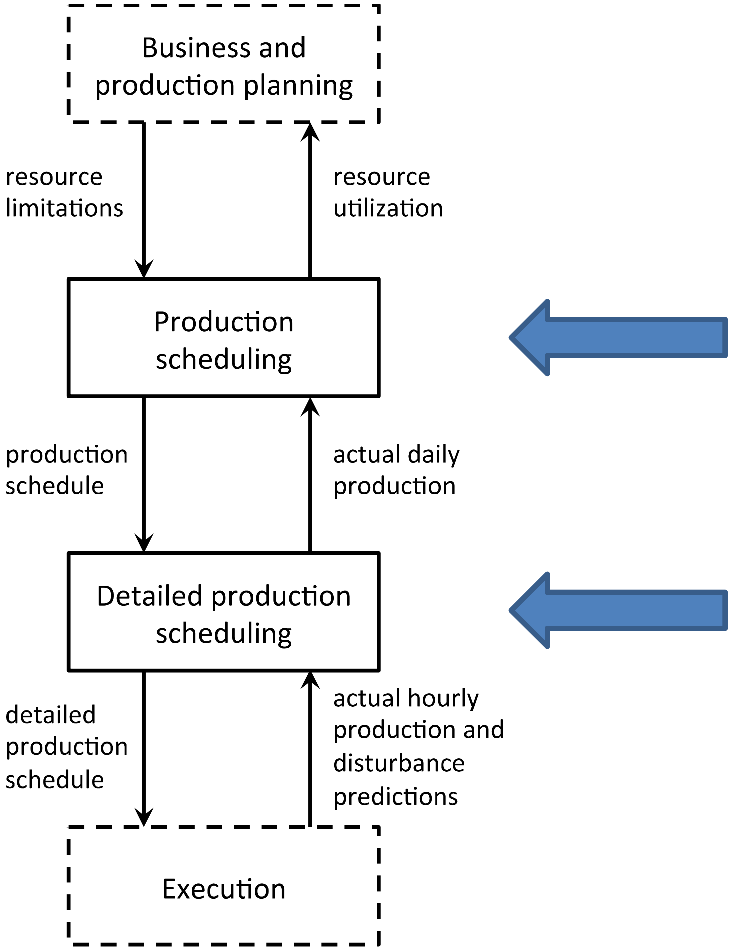
Hierarchical structure for scheduling



Disturbances related to orders, forecasts, transports

Disturbances in utilities, raw materials

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Production scheduling (PS)

- Makes a production schedule for one month
- Updates the schedule every day
- Inputs: orders and forecasted orders, actual daily production the previous day (reported from DPS)
- Output: production schedule (production, sales, and inventory level trajectories)
- The production schedule is sent as a reference to the DPS.

Detailed production scheduling (DPS)

- Makes a detailed production schedule for one day
- Updates the schedule every hour
- Inputs: reference values for production, sales, and inventory levels (reported from PS) and predicted disturbance trajectories
- Output: detailed production schedule (production, sales, and inventory trajectories)
- Accumulated production during the day is reported to the PS.

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Scheduling specifications

What do we need to consider to build realistic optimization models for the production scheduling?

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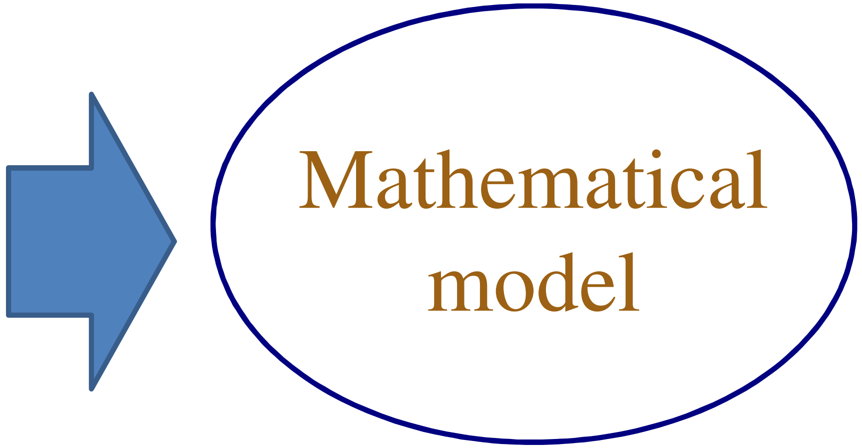
Scheduling specifications

- Area interconnections
- Disturbances in utilities, raw materials, equipment and transports
- Orders and forecasts
- Production rate limitations
- Inventory limitations
- Inventory costs
- Start-up costs and start-up times
- Market conditions
- Costs for late delivery
- Cost of production rate changes



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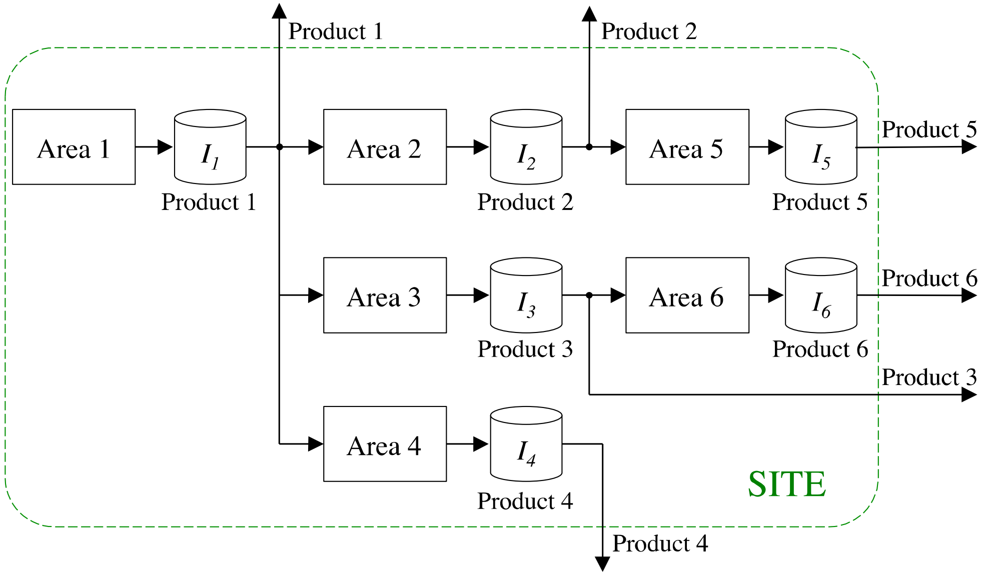
An example



Background data:

- Max- and min production
- Contribution margins
- Start-up times
- Max- and min inventory levels
- Reference intervals for inventories
- Orders and forecasts
- Utility usage

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Production scheduling

$$\text{minimize} \sum_{i\in\mathcal{A}} \sum_{\tau=1}^{N_{PS}} \left[\alpha_i m_i B_{i\tau} - \beta_i m_i q_{i\tau}^F + \gamma_i s_{i\tau} + \delta_i z_{i\tau} + \epsilon_i x_{i\tau}\right]$$

backlog | forecasts | start-ups | reference buffer interval | prod. rate changes

subject to constraints

- area interconnections
- prod. rate limitations
- inventory limitations
- start-up times
- market conditions

→ Mixed-integer linear program

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Detailed production scheduling

$$\text{minimize} \sum_{i \in \mathcal{A}} \sum_{t=1}^{N_{DPS}} \Big[(I_{it} - I_i^{\text{ref}})^2 \zeta_i + (q_{it} - q_i^{\text{ref}})^2 \eta_i +$$

buffer tank levels — prod. rates

$$+ (q_{it}^m - q_i^{m,\text{ref}})^2 \theta_i + \kappa_i s_{it} + \lambda_i x_{it} \Big]$$

sales — start-ups — prod. rate changes

subject to constraints

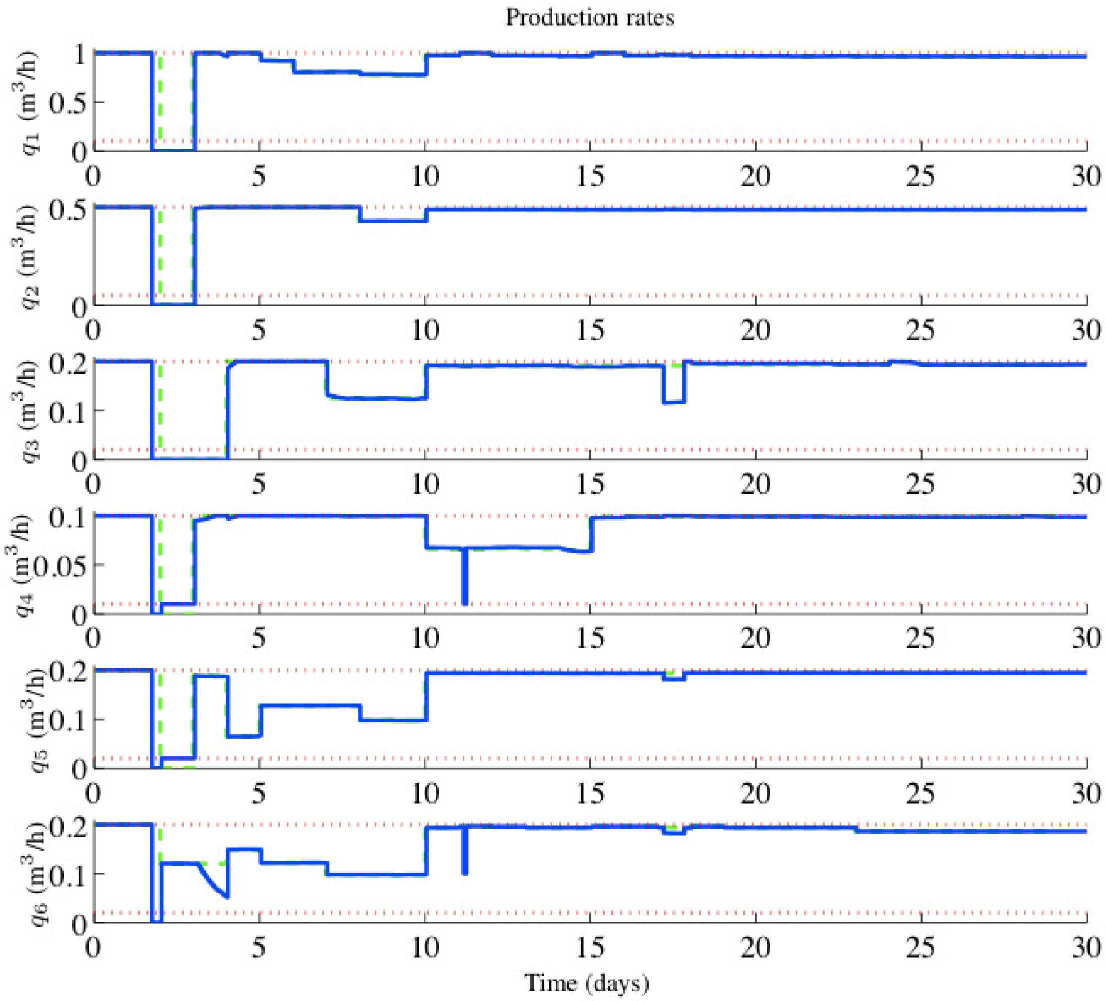
- area interconnections
- prod. rate limitations
- inventory limitations
- start-up costs
- market conditions
- utility usage

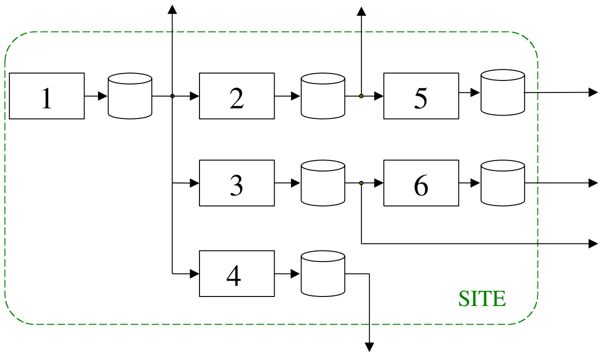
⇒ Mixed-integer quadratic program

Simulation

- Simulation time 30 days
- Initial plan given by order volumes
- Three simulated utility disturbances
  - Electricity disturbance at day 2 (off for 2 hours) (required by all areas)
  - Steam disturbance at day 12 (30% for 2 hours) (required by area 4 and 6)
  - Cooling water disturbance at day 18 (80% for 15 hours) (required by area 3, 5, and 6)

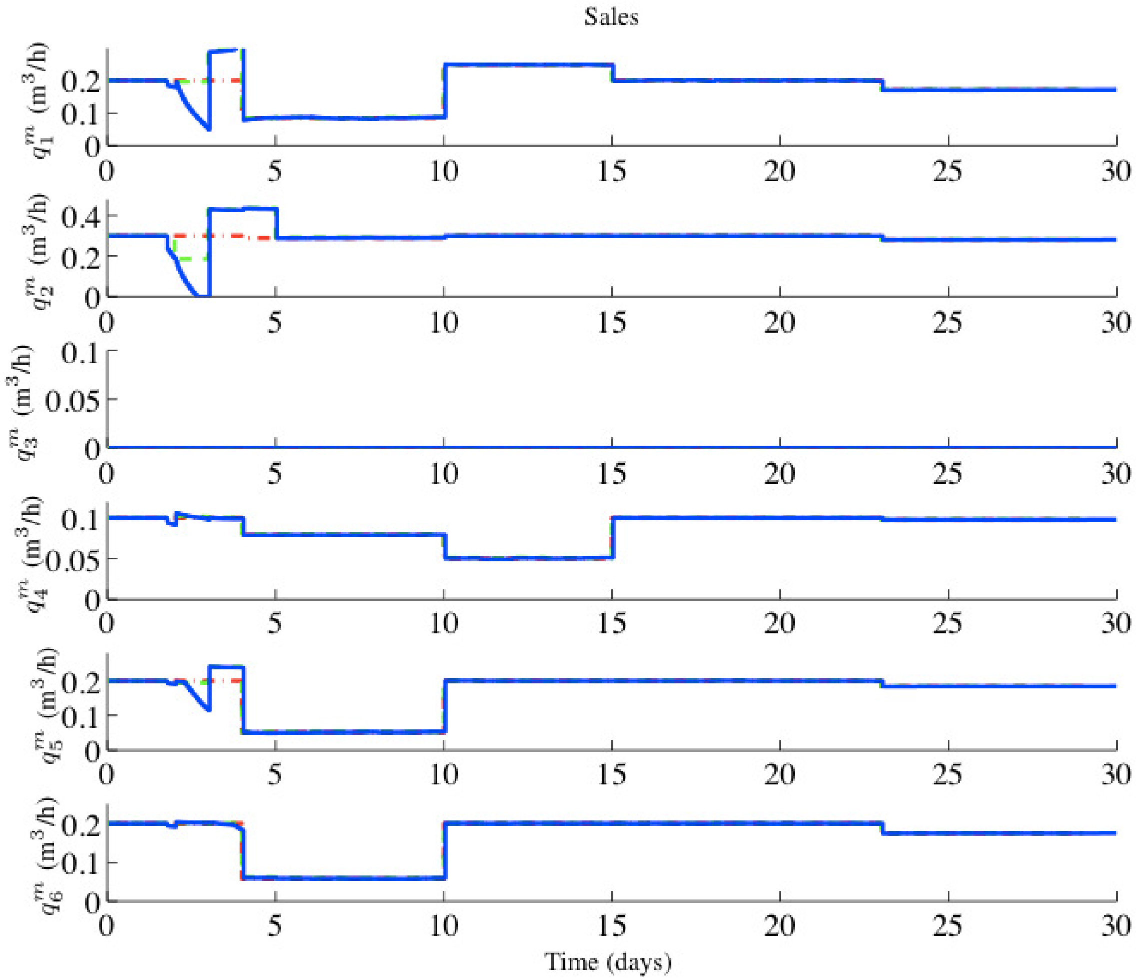
Simulation results – production rates

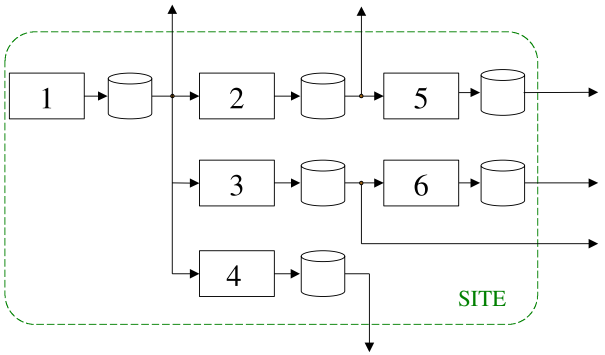




- Electricity, day 2 (all areas)
- Steam, day 12 (area 4, 6)
- Cooling water, day 18 (area 3, 5, 6)

Simulation results – sales





- Electricity, day 2 (all areas)
- Steam, day 12 (area 4, 6)
- Cooling water, day 18 (area 3, 5, 6)

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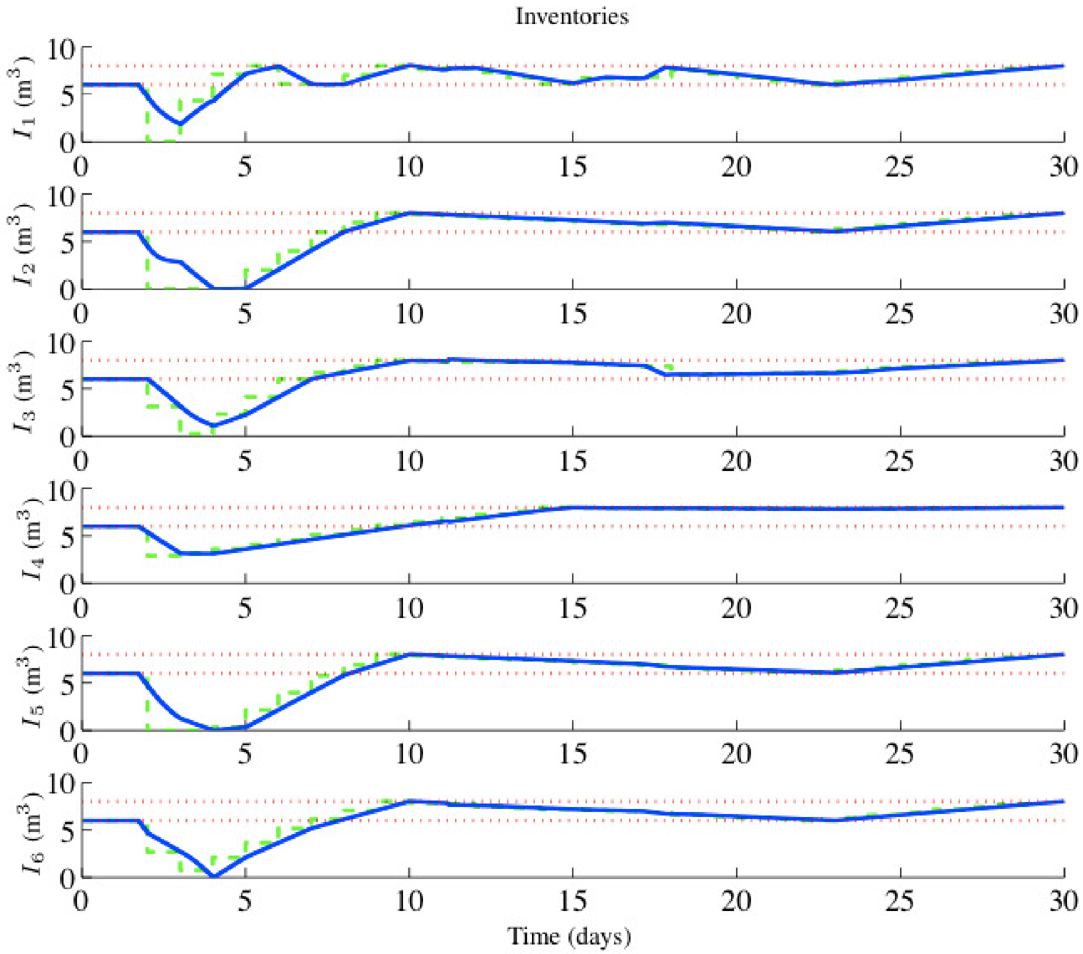
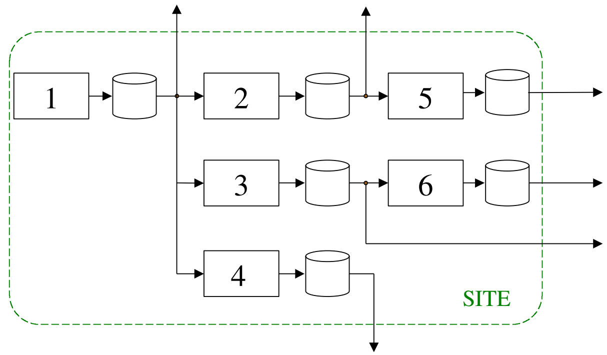
Simulation results – inventories





- Electricity, day 2 (all areas)
- Steam, day 12 (area 4, 6)
- Cooling water, day 18 (area 3, 5, 6)

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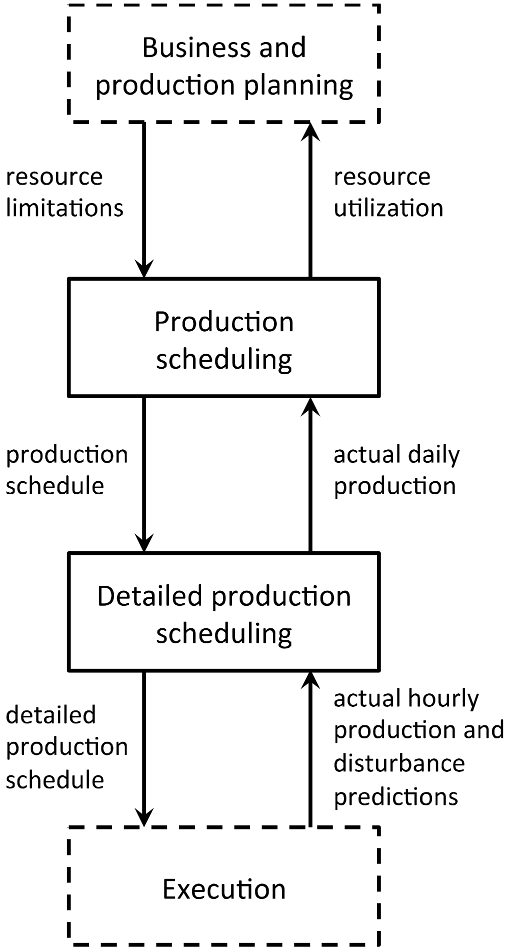
Results



- The DPS follows the PS reference well when there are no disturbances.
- At disturbances, the DPS handles them in an economically optimal way. The PS updates its plan to account for backlog.
- The inventories are utilized to handle disturbances.

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Conclusions

- The impact of disturbances in utilities/raw materials/equipment is difficult to predict for sites with several connected areas

- Site operators/managers have to decide on how to operate the site to minimize the economical impact of the disturbance, while keeping the long-term planning goals in mind

  ➡ Need for decision support

- Model-based production planning tools are today uncommon within the process industry (mostly spreadsheets)

Thank you for listening!

Questions?