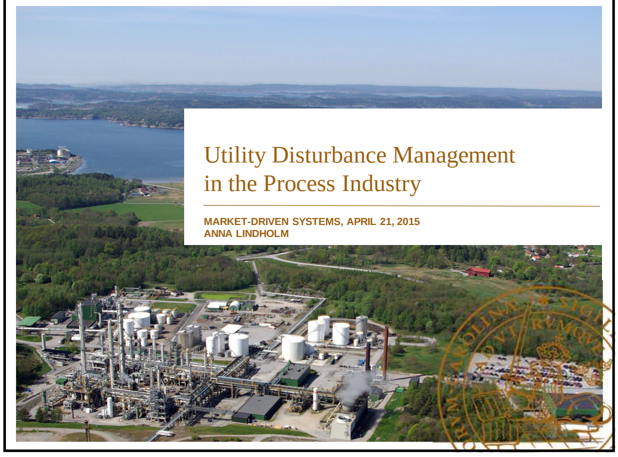


Utility Disturbance Management in the Process Industry

MARKET-DRIVEN SYSTEMS, APRIL 21, 2015
ANNA LINDHOLM

About me

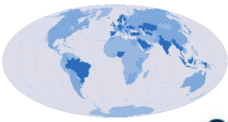
- PhD in Automatic Control, Lund University
- Defended my PhD thesis *"Hierarchical Scheduling and Utility Disturbance Management in the Process Industry"* in October 2013
- Research within process industrial centre, collaboration with Perstorp
- Work at ÅF in Malmö since March 2014

ÅF

- Consulting firm with around 7000 employees
- Assignments all over the world (80+ countries in 2013)

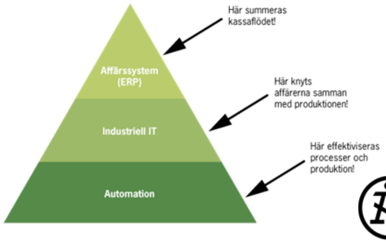
Major customers:

- Volvo
- Ericsson
- Oslo Airport
- Scania
- Power Machines
- Vattenfall
- Trafikverket
- Försvarets materielverk
- Tetra Pak



ÅF Industrial IT

ÅF Industrial IT helps companies connect business with production to be able to produce better and more profitably, by a unique combination of IT and operational expertise.



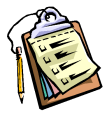
ÅF Industrial IT

Solutions

- MES, Manufacturing Execution Systems
- System integration
- Production planning, simulation, optimization, traceability and quality assurance
- Manufacturing Intelligence
- Batch solutions
- EMS, Energy Management System
- OEE, Overall Equipment Effectiveness
- Own concepts for industry-specific solutions

Agenda

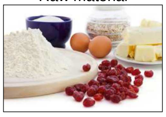
- What is a utility?
- Disturbances in utilities
- The UDM method
- Utility performance indicators
- Calculations – estimation of revenue loss
- Case study at Perstorp
- Dynamic modeling of a site
- Optimizing the supply of utilities at disturbances
- Utility disturbance management and production planning



What is a utility?

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

Raw material



Equipment

Utilities

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

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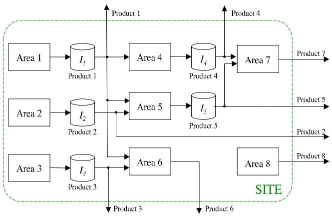
A process industrial site



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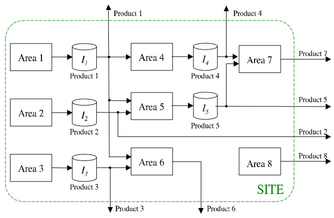
Disturbances in utilities



Disturbances in utilities

- affect many areas at a site, directly or indirectly
- are common within the process industry

It could be difficult to determine the root cause because of utility inter-dependence

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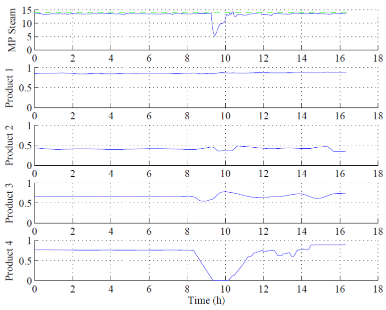
An industrial example (1)

Example 1: Pressure drop in middle-pressure steam net



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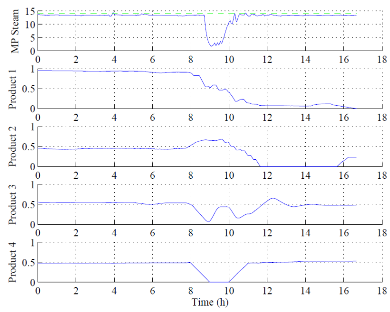
An industrial example (2)

Example 2: Pressure drop in middle-pressure steam net



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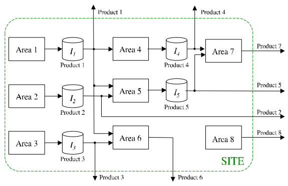
Challenges

- How do we find out which utilities that contribute to the greatest losses at a site?
- How should a site be operated in order to minimize the economical effects of disturbances in production?
- How should we choose the inventory levels?
- How does utility disturbance management relate to production planning?



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

Workflow for finding utility disturbance management strategies

- Calculate key performance indicators for utilities
- Use key performance indicators to estimate losses for a past time period
- Use result to come up with proactive strategies for reducing the losses

or

- Do more advanced modeling to get reactive strategies

The Utility Disturbance Management (UDM) method

Disturbances in utilities

Assumption: No negative effect on production as long as the utility operates within limits.

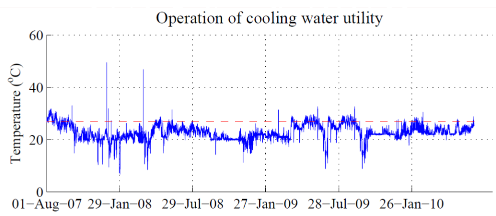
➡ can set limits for when a utility starts to have negative impact on production

- Steam: Steam pressure outside certain limits
- Cooling water: Cooling water temperature outside certain limits
- …

➡ utility disturbances can be identified directly from measurement data

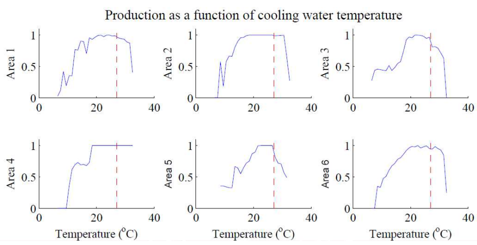
Disturbances in utilities – An Example

Example: Cooling water temperature



Validation of limits

Example: Cooling water temperature



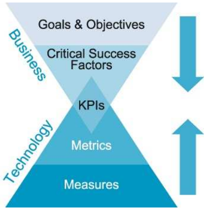
Key performance indicators (KPIs)

New key performance indicators for utilities:

Utility availability

Direct Area availability

Total Area availability



Utility availability

Definition: *Utility availability* is the fraction of time all utility parameters are inside their critical limits

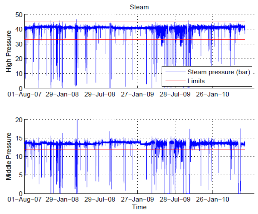
Utility availability – An example

Steam utility

Disturbance limits, pressure *p*

High pressure steam: *p* < 33 bar or *p* > 45 bar

Middle pressure steam: *p* < 12 bar



Utility availability
95.94 %

Utility – Area connection

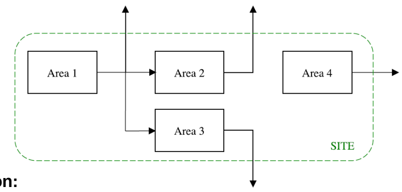
Each area at a site requires a specific set of utilities.

	Area 1	Area 2	Area 3	Area 4
Steam	x	x		
Cooling water	x	x	x	x
Electricity	x	x	x	x
Water	x		x	
Nitrogen	x	x	x	x
Compressed air	x	x	x	x
Water treatment		x		x

Direct area availability

Definition: The *direct area availability* is the fraction of time all utility parameters for all utilities needed at an area are inside their critical limits.

Total area availability



Definition:

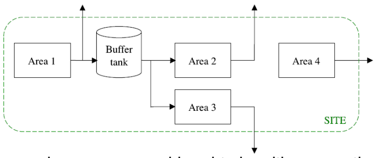
The *total area availability* is the fraction of time all utility parameters for all utilities needed at an area are inside their critical limits

AND

all areas which the area is dependent on are available

Use KPIs to estimate revenue loss at disturbances

On/off production modeling

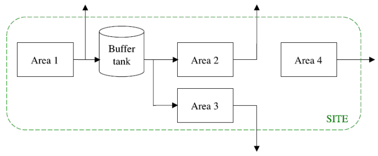


- Utilities and areas are considered to be either operating or not operating, i.e., 'on' or 'off'
- An area operates at maximum production speed when available, and does not produce when not available
- Can take buffer tanks between areas into account if necessary

Calculations

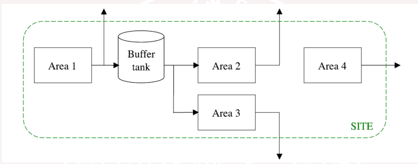
How can the key performance indicators for utilities be calculated in an efficient way?

➡ use a matrix representation of areas and utilities



Calculations – Area interconnections

Representation of the interconnection of production areas



Area dependence matrix

$$A_d = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(size $n_a \times n_a$)

Calculations – Measurement data

Representation of utility measurement data

$$\begin{aligned}
\text{steam} &= [42\ 38\ 34\ 32\ 35\ 41\ 40\ 36\ 34\ 37] \\
\text{cooling water} &= [25\ 24\ 24\ 26\ 28\ 30\ 27\ 25\ 24\ 25] \\
\text{electricity} &= [1\ 1\ 1\ 1\ 1\ 1\ 0\ 1\ 1\ 1] \\
\text{feed water} &= [22\ 19\ 18\ 20\ 22\ 21\ 21\ 21\ 21\ 21] \\
\text{instrument air} &= [1\ 2\ 1\ 1\ 3\ 2\ 1\ 0\ 0\ 1]
\end{aligned}$$

Disturbance limits:

Steam :	pressure < 35 bar
Cooling water :	temperature $> 27°C$
Electricity :	on/off
Feed water :	pressure < 20 bar
Instrument air :	pressure ≤ 0 bar

Calculations – Utility operation

Utility operation matrix

$$U = \begin{bmatrix} 1 & 1 & 0 & 0 & 1 & 1 & 1 & 1 & 0 & 1 \\ 1 & 1 & 1 & 1 & 0 & 0 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 0 & 1 & 1 & 1 \\ 1 & 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 0 & 0 & 1 \end{bmatrix}$$

(size $n_u \times n_s$)

Calculations – Utilities requirements

Utility requirements

	Area 1	Area 2	Area 3	Area 4
Steam	x		x	
Cooling water		x	x	
Electricity	x	x	x	x
Feed water	x		x	
Instrument air	x		x	x

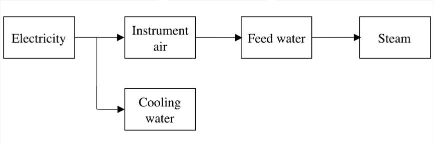
Area-utility matrix

$$A_u = \begin{bmatrix} 1 & 0 & 1 & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 \end{bmatrix}$$

(size $n_a \times n_u$)

Calculations – Utility interdependence

Utility dependence



Utility dependence matrix

$$U_d = \begin{bmatrix} 1 & 0 & 1 & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 \end{bmatrix}$$

(size $n_u \times n_u$)

Calculations

Using the general matrix representation, it is possible to:

- Remove utility dependence
- Compute utility availability
- Compute direct and total area availability
- Estimate revenue losses for areas and utilities (on/off modeling)

Calculations

Remove utiity dependence from *U*

$$U_{ud} = \text{sign}\left(U + \text{sign}\left((I - U_d)(U - \mathbf{1}\mathbf{1}^T)\right)\right)$$

Compute utility availability

$$U_{av} = U \cdot \mathbf{1}/n_s$$

Direct area availability

$$A_{av}^{dir} = A_{dir} \cdot \mathbf{1}/n_s$$

$$A_{dir} = \mathbf{1}\mathbf{1}^T + \text{sign}\left(A_u(U - \mathbf{1}\mathbf{1}^T)\right)$$

Total area availability

$$A_{av}^{tot} = A_{tot} \cdot \mathbf{1}/n_s$$

$$A_{tot} = \mathbf{1}\mathbf{1}^T + \text{sign}\left(A_d(A_{dir} - \mathbf{1}\mathbf{1}^T)\right)$$

Estimate direct revenue loss in each area

$$J_p^{dir} = \left(\mathbf{1} - A_{av}^{dir}\right) .* q^m .* p n_s t_s$$

Estimate total revenue loss in each area

$$J_p^{tot} = \left(\mathbf{1} - A_{av}^{tot}\right) .* q^m .* p n_s t_s$$

Estimate direct revenue loss due to each utility

$$J_u^{dir} = \text{diag}\left[\mathbf{1} - U_{av}^{ud}\right] \cdot A_u^T (q^m .* p) n_s t_s$$

Estimate total revenue loss due to each utility

$$J_u^{tot} = \text{diag}\left[\mathbf{1} - U_{av}^{ud}\right] \cdot \text{sign}\left(A_d A_u\right)^T (q^m .* p) n_s t_s$$

Calculations – Notation

n_a number of areas

n_b number of buffer tanks

n_u number of utilities

n_s number of samples

t_s sampling time

$p = \begin{bmatrix} p_1 & p_2 & \dots & p_{n_a} \end{bmatrix}^T$ contribution margins

$q = \begin{bmatrix} q_1 & q_2 & \dots & q_{n_a} \end{bmatrix}^T$ production

$q^m = \begin{bmatrix} q_1^m & q_2^m & \dots & q_{n_b}^m \end{bmatrix}^T$ flows to the market

$V = \begin{bmatrix} V_1 & V_2 & \dots & V_{n_b} \end{bmatrix}^T$ buffer tank levels

$$\mathbf{1}\mathbf{1}^T = \begin{bmatrix} 1 \\ 1 \\ \dots \\ 1 \end{bmatrix} \cdot \begin{bmatrix} 1 & 1 & \dots & 1 \end{bmatrix} = \begin{bmatrix} 1 & 1 & \dots & 1 \\ 1 & 1 & \dots & 1 \\ \vdots & \vdots & \ddots & 1 \\ 1 & 1 & \dots & 1 \end{bmatrix}$$

$$\text{sign}(x) = \begin{cases} 1 & x \geq 0 \\ 0 & x = 0 \\ -1 & x \leq 0 \end{cases}$$

$.*$ notes elementwise multiplication of vectors

$\text{diag}\left[\text{X}\right]$ notes a diagonal matrix with the elements of the vector X on the diagonal

Case study at Perstorp

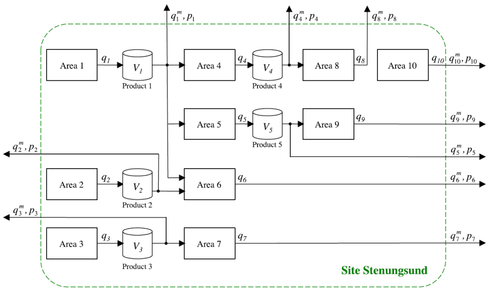
- UDM method applied to site Stenungsund, Perstorp
- On/off production modeling without buffer tanks

Site Stenungsund Located on the Swedish west coast, 50 km north of Gothenburg.

Main products: Aldehydes, organic acids, alcohols, plasticizers

Perstorp
WINNING FORMULAS

Flowchart of the site



Utility requirements

	1	2	3	4	5	6	7	8	9	10
HP steam							x	x	x	x
MP steam	x	x	x	x	x	x	x		x	
Cooling water	x	x	x	x	x	x	x	x	x	x
Cooling fan 1	x									
Cooling fan 2		x								
Cooling fan 3			x							
Cooling fan 7							x			
Electricity	x	x	x	x	x	x	x	x	x	x
Water treatment	x	x	x	x	x	x		x	x	
Flare	x	x	x	x	x	x				x
Combustion device 7							x			
Combustion device 9									x	
Nitrogen	x	x	x	x	x	x	x	x	x	x
Feed water	x	x	x	x	x			x		
Instrument air	x	x	x	x	x	x	x	x	x	x
Vacuum system	x	x	x	x	x	x	x	x	x	x

Summary of case study problem

- 10 production areas
- 15 utilities
- 5 internal buffer tanks
- August 1, 2007 – July 1, 2010
- Planned stop September 15 – October 8, 2009
- Sampling interval 1 minute

$\Rightarrow$ Size $15 \times 1\,501\,921$ of the utility operation matrix

Case study matrices

$$A_d = \begin{bmatrix} 1&0&0&0&0&0&0&0&0&0\\ 0&1&0&0&0&0&0&0&0&0\\ 0&0&1&0&0&0&0&0&0&0\\ 1&0&0&1&0&0&0&0&0&0\\ 1&0&0&0&1&0&0&0&0&0\\ 1&1&0&0&0&1&0&0&0&0\\ 0&0&1&0&0&0&1&0&0&0\\ 1&0&0&1&0&0&0&1&0&0\\ 1&0&0&0&1&0&0&0&1&0\\ 0&0&0&0&0&0&0&0&0&1 \end{bmatrix}$$

$$U_d = \begin{bmatrix} 1&0&0&0&0&0&0&1&0&0&0&0&1&1\\ 0&1&0&0&0&0&0&1&0&0&0&0&1&1\\ 0&0&1&0&0&0&0&1&0&0&0&0&0&0\\ 0&0&0&1&0&0&0&1&0&0&0&0&0&0\\ 0&0&0&0&1&0&0&1&0&0&0&0&0&0\\ 0&0&0&0&0&1&0&1&0&0&0&0&0&0\\ 0&0&0&0&0&0&1&1&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&1&0&0&0&0&0&0\\ 0&0&0&0&0&0&0&1&1&0&0&0&0&1\\ 0&0&0&0&0&0&0&1&0&1&0&0&0&1\\ 0&0&0&0&0&0&0&1&0&0&1&0&0&1\\ 0&0&0&0&0&0&0&1&0&0&0&1&0&0\\ 0&0&0&0&0&0&0&1&0&0&0&0&1&1\\ 0&0&0&0&0&0&0&1&0&0&0&0&0&1 \end{bmatrix}$$

$$A_u = \begin{bmatrix} 0&1&1&1&0&0&0&1&1&1&0&0&1&1&1\\ 0&1&1&0&1&0&0&1&1&1&0&0&1&1&1\\ 0&1&1&0&0&1&0&1&1&1&0&0&1&1&1\\ 0&1&1&0&0&0&0&1&1&1&0&0&1&1&1\\ 0&1&1&0&0&0&0&1&1&1&0&0&1&1&1\\ 0&1&1&0&0&0&0&1&1&1&0&0&1&0&1\\ 1&1&1&0&0&0&1&1&0&0&1&0&1&0&1\\ 1&0&1&0&0&0&0&1&1&0&0&0&1&1&1\\ 1&1&1&0&0&0&0&1&1&0&0&1&1&0&1\\ 1&0&1&0&0&0&0&1&0&1&0&0&1&0&1 \end{bmatrix}$$

Calculated utility and area availabilities

Utility	Availability (%)
Flare	100
Vacuum systems	100
Water treatment	100
Instrument air	100
Cooling fan area 7	100
Nitrogen	100
Electricity	99
Feed water	99
HP steam	99
Cooling fan area 1	97
Cooling fan area 2	97
Cooling fan area 3	97
MP steam	97
Combustion area 9	96
Combustion area 7	94
Cooling water	92

Area	Direct availability (%)	Total availability (%)
1	84	84
2	84	84
3	84	84
4	87	84
5	87	84
6	87	84
7	82	80
8	89	84
9	84	81
10	90	90

Estimated revenue loss caused by each utility

Direct loss	Total loss
Cooling water	Cooling water
MP steam	MP steam
Combustion device 9	Cooling fan 1
Combustion device 7	Feed water
Cooling fan 1	Combustion device 9
Electricity	Combustion device 7
HP steam	Electricity
Feed water	HP steam
Nitrogen	Cooling fan 2
Cooling fan 3	Cooling fan 3
Cooling fan 2	Nitrogen
Instrument air	Instrument air
Cooling fan 7	Cooling fan 7
Flare	Flare
Water treatment	Water treatment

greatest loss

smallest loss

Case study conclusions

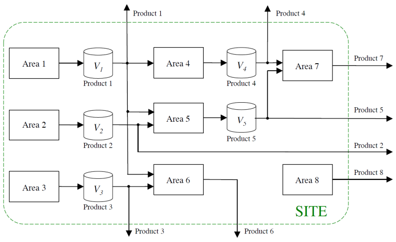
The cooling water utility seems to cause the greatest losses at site Stenungsund

➡ Try to improve availability of cooling water utility by proactive disturbance management

➡ Do more advanced modeling to obtain reactive disturbance management strategies for disturbances in cooling water (and other utilities)

Dynamic modeling of a site

Idea: Do a rough dynamic model of a site and its utilities to obtain reactive disturbance management strategies (decision support)



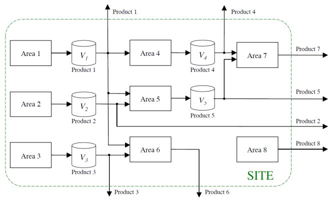
Dynamic modeling of a site

Assume that the production in an area is directly proportional to the inflows to the area

$q_{jk}^{\text{in}}(t) = q_k(t) a_{jk}$

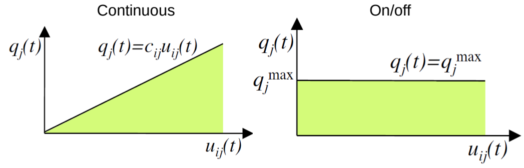
Buffer tanks give dynamics according to

$\frac{dV(t)}{dt} = q_{in}(t) - q_{out}(t)$



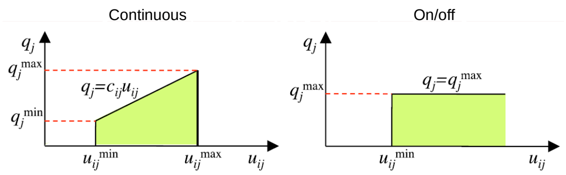
Dynamic modeling of utilities at a site

- Assume that each utility is a volume, or power, that is shared by all areas that require the utility
- Assume a linear relationship between assigned volume of the utility to an area and production in that area
- Distinguish between utilities with continuous characteristics and on/off characteristics



Dynamic modeling of utilities at a site

With maximum and minimum constraints on production:

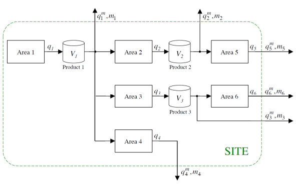


Utilities are shared between production areas:

$$\sum_{j \in \mathcal{M}_i} u_{ij}(t) \leq U_i(t)$$

Formulating a dynamic optimization problem

Mass balance



With conversion factors $a_{jk} = 1$ (for simplicity), we get the mass balances

$$V_1(t+1) = V_1(t) + q_1(t) - q_1^m(t) - q_2(t) - q_3(t) - q_4(t)$$
$$V_2(t+1) = V_2(t) + q_2(t) - q_2^m(t) - q_5(t)$$
$$V_3(t+1) = V_3(t) + q_3(t) - q_3^m(t) - q_6(t)$$

Formulating a dynamic optimization problem

More Constraints

Buffer tank levels

$$V_1^{\min} \leq V_1(t) \leq V_1^{\max}$$
$$V_2^{\min} \leq V_2(t) \leq V_2^{\max}$$
$$V_3^{\min} \leq V_3(t) \leq V_3^{\max}$$

Production rates

$$q_i^{\min} + s_i(t) \leq q_i(t) \leq q_i^{\max}$$
$$-q_i^{\min} \leq s_i(t) \leq 0$$

Constraints due to shared utilities

Continuous

$$\sum_{j \in \mathcal{M}_i} \frac{1}{c_{ij}} q_j(t) - \frac{m_{ij}}{c_{ij}} \leq U_i(t)$$

On/off

$$q_j(t) \leq \begin{cases} q_j^{\max} & \text{if } U_i(t) = 1 \\ 0 & \text{if } U_i(t) = 0, \end{cases} \qquad j \in \mathcal{M}_i$$

Area →	1	2	3	4	5	6
Steam HP	x		x			
Steam MP		x		x		x
Cooling water	x	x	x	x	x	x

$$k_{11}q_1(t) + k_{13}q_3(t) \leq U_1(t)$$
$$k_{22}q_2(t) + k_{24}q_4(t) + k_{26}q_6(t) \leq U_2(t)$$
$$\sum_{j=1}^{6} k_{3j}q_j(t) \leq U_3(t)$$

Formulating a dynamic optimization problem

Cost function

$$J_t = (p^T q^m(t) - p_{ref})^2 Q_p + \Delta V^T(t) Q \Delta V(t) + \Delta q^T(t) R \Delta q(t)$$
$$- g^T s(t) + s^T(t) Q_s s(t)$$

where $\Delta V(t) = V(t) - V_{ref}$

$\Delta q(t) = q(t) - q_{ref}$

Dynamic optimization

$$\text{minimize} \sum_{\tau=0}^{N-1} J_t\left(q(\tau), q^m(\tau), V(\tau), s(\tau)\right)$$

subject to constraints

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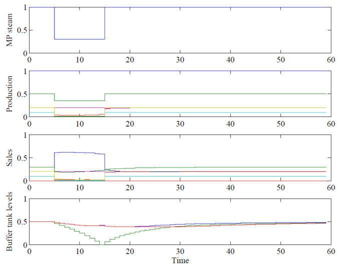
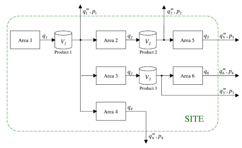
Solution to example problem

Disturbance in MP steam – 30% of normal capacity for 10 hours

MP steam is required at areas 2, 4, and 6





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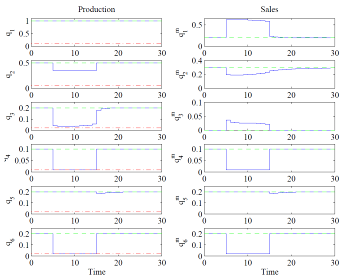

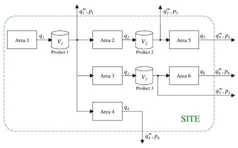

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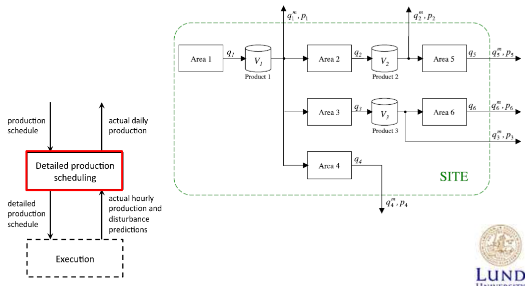
Utility disturbance management and production planning



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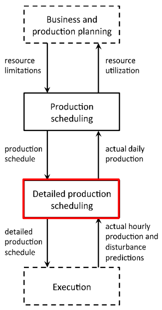
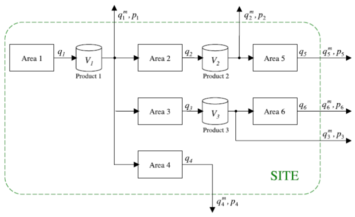
Utility disturbance management and production planning





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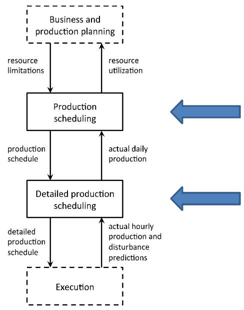
Hierarchical structure for scheduling



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

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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 utility 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

→ Mathematical models

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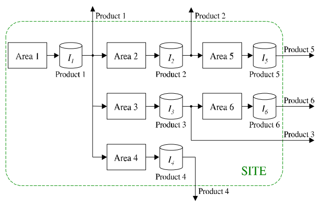
An example



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

$$\text{minimize} \sum_{i \in \mathcal{A}} \sum_{\tau=1}^{N_{PS}} \left[\underbrace{\alpha_i m_i B_{i\tau}}_{\text{backlog}} - \underbrace{\beta_i m_i q_{i\tau}^F}_{\text{forecasts}} + \underbrace{\gamma_i s_{i\tau}}_{\text{start-ups}} + \underbrace{\delta_i z_{i\tau}}_{\text{reference buffer interval}} + \underbrace{\epsilon_i x_{i\tau}}_{\text{prod. rate changes}} \right]$$

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

$$\text{minimize} \sum_{i\in\mathcal{A}} \sum_{t=1}^{N_{DPS}} [\underbrace{(I_{it} - I_i^{\text{ref}})^2\zeta_i}_{\text{buffer tank levels}} + \underbrace{(q_{it} - q_i^{\text{ref}})^2\eta_i}_{\text{prod. rates}} + \underbrace{(q_{it}^m - q_i^{m,\text{ref}})^2\theta_i}_{\text{sales}} + \underbrace{\kappa_i s_{it}}_{\text{start-ups}} + \underbrace{\lambda_i x_{it}}_{\text{prod. rate changes}}]$$

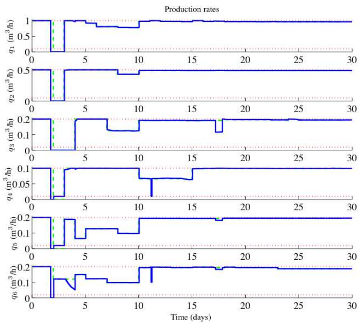
subject to constraints
- area interconnections
- prod. rate limitations
- inventory limitations
- start-up costs
- market conditions
- utility usage

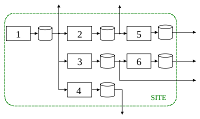
→ Mixed-integer quadratic program

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)

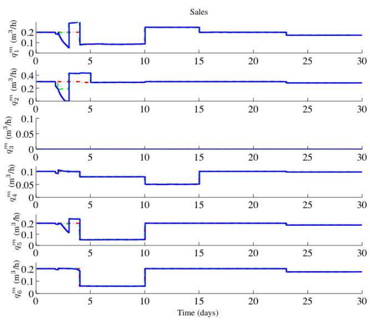
Simulation results – production rates

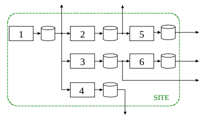




- Electricity, day 2 (all areas)
- Steam, day 12 (area 4, 6)
- Cooling water, day 18 (area 3, 5, 6)

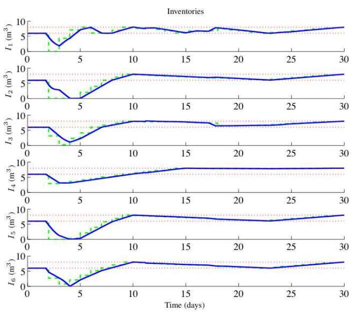
Simulation results – sales

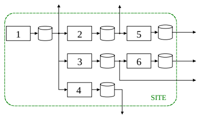




- Electricity, day 2 (all areas)
- Steam, day 12 (area 4, 6)
- Cooling water, day 18 (area 3, 5, 6)

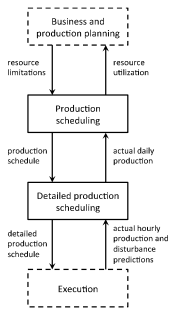
Simulation results – inventories





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

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.

Summary

- Utilities are crucial at industrial sites and lead to great losses if they are not functioning correctly
- The effects of utility disturbances are hard to predict since they are often used at many areas, and areas could be connected
- Key performance indicators for utilities may be used to quickly estimate the loss caused by each utility at the site
- Dynamic optimization can be used to obtain decision support for how to handle utility disturbances (how to control production)
- Handling of utility disturbances is closely connected to production planning/scheduling

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Thank you for listening!

Questions?

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