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Operations and investment optimisation in steam networks

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Optimal network operations & Resilient investments

**Optimal operations**
- Optimal distribution of steam from producers to consumers through a steam network

**Undercapacity & load shedding**
- Optimal operations facing under capacity

**Optimal investments**
- Designing least cost solutions

**Operations with boiler failures**
- Simulation of boiler failures to identify realistic network operations

**Steam network resilience**
- Identifying and evaluating resilient investment solutions
Steam networks

Introduction

Steam network overview
Petrochemical and refining cluster

Site 1

Central Boiler

Site 2
Petrochemical and refining cluster

Site 1 - Refining
- HP Boiler 1
- HP Boiler 2
- Central Boilers
  - HP boilers
    - 91b

Site 2 - Petrochemistry
- HP Boiler 1
- HP Boiler 2
- HP Boiler 3

90b
- 90/20
- Desup
- 90/20

30b
- 90/30
- Desup
- 90/5

20b
- 20/5

5b
- Units
- Utilities

5b
- Utilities
- COND
- Units
Demand = consumption - internal production

**Site 1**
Mean demand: 163 t/h  
Max demand: 207 t/h  
Available capacity: 180 t/h

**Site 2**
Mean demand: 339 t/h  
Max demand: 475 t/h  
Available capacity: 390 t/h
Operations optimisation

- match production and consumption
- produce electric safety net
- avoid atmospheric venting

- minimise operational costs
  maximise turbine use
  activate letdowns + desuperheaters if demand high

self regulating in a ‘healthy’ steam network but not trivial!
MILP formulation

- header mass balance
- turbines: constant isentropic efficiency
- letdowns: steam outlet is multiplied by a factor [1.03 - 1.1]

- boilers production is variable
- process units consumption/production is set as a parameter

- objective: minimise operational costs

\[ \text{Obj} = \min \text{OPEX} \]
Case study - optimal operations

**natgas**: 20 €/MWh

mean/max

- CB HP Boilers: 9/76
- S1 Desup: 2/13
- S1 Units: 30/51
- S1 Boilers: 168/180
- S2 Desup: 6/25
- S2 Units: 126/203
- S2 Boilers: 332/390

Costs, load duration curves,...
Undercapacity

demand > available capacity

- extreme weather events
  steam pipes drenched in water leading to condensation
cold winds

- boilers offline
  planned maintenance and turn arounds
unplanned boiler trips

- exceptional demand
  unit startups
ageing catalysts/processes

- combinations of events

load shedding - taking units offline

- unit activation as integer variable

- penalty costs
  a financial penalty is applied for each unit taken offline

- shedding priority
  units go offline in a specific order (order of importance)
Petrochemical and refining cluster

Site 1 - Refining

- HP Boiler 1
- HP Boiler 2
- 90b
- 90/20
- Desup
- 20b
- 20/5
- 5b
- Units
- Utilities

Central Boilers

- HP boilers
- 91b

Site 2 - Petrochemistry

- HP Boiler 1
- HP Boiler 2
- HP Boiler 3
- 90b
- 90/20
- Desup
- 20b
- 20/5
- 30b
- 30/5
- Desup
- 5b
- Utilities
- COND
- Units
Case study - permanent boiler failure

Maximum production: 830 t/h

Load shedding

Demonstration

Demand

Supply
Investment optimisation

- identify least cost investments to supply steam
- fixed and variable investment costs
Case study - investment options to replace Central Boilers

Investment options:

\[ \text{Obj} = \min \sum_{n} \text{CAPEX}_n + \sum_{nt} (\text{OPEX}_{nt} + \text{PENALTY}_{nt}) \]
Case study - optimal choice in equipments
Dealing with boiler maintenance

- **oversized systems**
  - overcome unexpected events
  - allow normal operations under extreme conditions
  - planned maintenance operations
Case study - maintenance?

Investments

Demonstration
Case study - maintenance?
Case study - proposed resilient investment

Investments

Demonstration

Total CAPEX: 4.1 x10^6 €/yr
Dealing with boiler failures

Boilers fail...

- failures can occur randomly
- maintenance is planned
- boiler trips are not
  *murphy’s law*

How to define resilience

- ability to supply steam despite boiler trips
- network operability

- network simulation

<table>
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<th>Boiler max flow [t/h]</th>
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<tr>
<td>105</td>
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<td>140</td>
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Case study - simulation of random boiler failures

Simulated costs

- **Maximum penalty**: $12.5 \times 10^6$ euros
- **Investment**: $4.1 \times 10^6$ euros/yr
- **Operations**: $5.6 \times 10^6$ euros/yr
- **Penalty**: $3.8 \times 10^5$ euros/yr

Peak shedding

- **Site 1**
- **Site 2**

- **94.4% of runs have 99% operability**
Case study - sensitivity analysis / single boiler failure

[expected costs x10^6 €/yr]

Penalty: 0.4 0.8 0.9 1.3 5.5
Operations: 55.7 55.7 55.7 59.0 58.4
Investment: 4.1 4.1 4.1 4.1 4.1
Total: 60.2 60.7 60.7 64.4 68.0

% Runs with 99% operability
- All boilers online: 94.4%
- CB High pressure failure: 84.8%
- CB Medium pressure failure: 81.6%
- Site 1 HP failure: 65.2%
- Site 2 HP failure: 44.4%

Network simulation
Demonstration
Conclusion and outlook

accomplished

• operations optimisation
  optimal equipment choice
  load shedding
• investment optimisation
• network simulations
  evaluation of network resilience

weakness

• linear vs. non linear
• costing

further work

• key performance indicators
  e.g. Loss of Load Probability
• design of optimally resilient systems
  algorithm to optimally design investment suprastructure
Thank you for your attention