Master Thesis: Collaboration between Utility Systems and Production Plants under Time-sensitive Electricity Prices: Assessing the Economic Benefit

Case Study: An Integrated Steel Mill

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Energy-intensive industries are increasingly affected by time-sensitive electricity prices.
The sequential scheduling approach implies the risk of making suboptimal decisions.

Sequential (traditional) scheduling approach:
- Production scheduling
- Utility planning
- Interaction with power grid

Simultaneous (collaborative) scheduling approach:
- Production scheduling
- Utility planning
- Interaction with power grid

Production Plant

Utility System

Power Grid

Utility Demand

Utility Supply

Surplus Electricity

Purchased Electricity

Collaborative approach: Optimize utility system and production plant simultaneously while considering time-sensitive electricity prices.
A collaborative scheduling approach appears promising to the steelfinishing process

<table>
<thead>
<tr>
<th>Meltshop</th>
<th>Hot Rolling Mill</th>
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<tbody>
<tr>
<td><img src="image1" alt="" /></td>
<td><img src="image2" alt="" /></td>
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### Abbreviations:
- CO (coke oven)
- SP (sinter plant)
- BF (blast furnace)
- BOF (basic oxygen furnace)
- LF (ladle furnace)
- CC (continuous caster)
- SY (slab yard)
- RF (reheating furnace)
- HSM (hot strip mill)

1. Only excessive byproduct gases (CO gas, BF gas, BOF gas) that aren’t required in the CO, BF and BOF units are sent to the power plant.

### High Electricity Prices

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<tr>
<th>Use of surplus byproduct gases</th>
<th>Electricity generation</th>
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<tbody>
<tr>
<td>Natural gas consumption for reheating</td>
<td>Increased</td>
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<td>Reheating activity</td>
<td>Delayed</td>
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1. Abbreviations:  CO (coke oven), SP (sinter plant), BF (blast furnace), BOF (basic oxygen furnace), LF (ladle furnace), CC (continuous caster), SY (slab yard), RF (reheating furnace), HSM (hot strip mill)
An industrial case study is translated into a generic problem statement

**Given:**
- Hot rolling mill produces set of products \( s \in S \) with equipment \( e \in E \)
- Byproduct gases \( g \in G \) can be used for either reheating or to generate electricity
- Electricity can be purchased from or sold to the power grid at any time \( t \in T \)

**Determine:**
- The optimal production schedule for the hot rolling mill while satisfying customer demand at given due dates and meeting all process constraints
- Optimal byproduct gas distribution between the reheating furnaces and the power plant

1. Abbreviations: CO (coke oven), SP (sinter plant), BF (blast furnace), BOF (basic oxygen furnace), LF (ladle furnace), CC (continuous caster), SY (slab yard), RF (reheating furnace), HSM (hot strip mill)
2. Only excessive byproduct gases (CO gas, BF gas, BOF gas) that aren’t required in the CO, BF and BOF units are sent to the power plant
Logic constraints are used to translate the scheduling problem into a mathematical model.

**Objective function:**

Minimize operating costs of reheating furnaces and power plant

\[
\min \quad costs = c_{Fuel,RF} + c_{Fuel,PP} - r_{EL,PP}
\]

- Fuel costs of reheating furnaces
- Fuel costs of power plant
- Revenues from surplus electricity sales
Logic constraints are used to translate the scheduling problem into a mathematical model.

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<td>Power grid:</td>
<td>Time-sensitive electricity prices affect electricity sales and purchases</td>
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Real-world case study:
- 1 day planning horizon (10 min time intervals)
- 3 rolling programs: (2,667 tons per day)
- MILP ($\approx 106k$ 0-1 vars)
Energy Demand Reheating Furnaces over Time
(Collaborative scheduling, Spring EL price profile)

Reheating occurs during times of low electricity prices.

Natural gas demand only during times of peak energy demand.

Abbreviations: NG (natural gas), BFG (blast furnace gas), COG (coke oven gas), BOFG (basic oxygen furnace gas).
Electricity Generation over Time
(Collaborative scheduling, Spring EL price profile)

Electricity generation occurs during times of high electricity prices

Abbreviations: NG (natural gas), BFG (blast furnace gas), COG (coke oven gas), BOFG (basic oxygen furnace gas)
The economic benefits due to collaboration can be significant.

Profits generated in [$/day]:

Optimal timing of reheating and electricity generation exploits fluctuations in electricity prices and thereby increases the overall profit.
Energy Demand Reheating Furnaces over Time
(Collaborative scheduling, Summer EL price profile)

- Electricity Price
- Overall Reheating Load
- Load Share BOFG
- Load Share COG
- Load Share NG

Reheating occurs during times of low electricity prices.

Electricity prices higher and fluctuations less pronounced.

Natural gas demand only during times of peak energy demand.

Abbreviations: NG (natural gas), BFG (blast furnace gas), COG (coke oven gas), BOFG (basic oxygen furnace gas)
The economic benefits due to collaboration can be marginal.

Profits generated in [$/day]:

**Spring Day**
- Traditional Scheduling: $13,246
- Collaborative Scheduling: $15,996
  - $2,750 increase per day

**Summer Day**
- Traditional Scheduling: $44,902
- Collaborative Scheduling: $45,611
  - $709 increase per day

The economic benefit due to collaboration is very sensitive to the nature of the electricity price fluctuations.
Conclusion

Novelty of the work

- Quantification of the economic benefits of a collaborative scheduling approach
- Analysis of the sensitivity of the obtained results with respect to time-sensitive electricity prices
- Evidence that the absolute economic benefit is highly sensitive to the character of electricity price fluctuations
  - Moderate fluctuations: Small incentive for collaboration
  - Pronounced fluctuations: Significant economic benefit due to collaboration

Impact for industrial applications

- Ability to apply the developed modeling framework to other industries and quantitatively assess the potential economic benefits of collaboration
Thank you for your attention!

Questions, comments?

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