Modelling industrial flexibility from the electricity consumption and the human resources points of view

Thibaut Cuvelier, Quentin Louveaux — university of Liège
Context

What if November 2016 becomes usual?

Steel mill consumption: ~ 50 MWh / 100 tonnes
Thus...

electrical flexibility

• Flexibility is about exploiting those price fluctuations to lower the costs

• Some possible answers?
  • Use gas instead of electricity
  • Produce less and/or later
  • Don’t produce

• Not possible with all processes...
Example of result

Use the machines when the prices are low

Price scenario

High prices: low consumption

Low prices: high consumption

Melt (EAF)

Transform (LF)

Cast (CC)
What limitations flexibility?

• Price prediction: highly dependent on weather
  • Good predictions for a few days
  • Useless after a week

• What about the workers?
  • Schedule predictability
  • Schedules that barely impact health
Overview of this talk

- InduStore
- Methodology
  - Production model
  - HR model
- Evaluation
InduStore

Two goals: **quantify** and **exploit** electrical flexibility

http://www.industore-project.be/
InduStore highlights energy flexibility in industrial sites

- How sizeable is flexibility?
- How to reconcile flexibility and workers well-being?
- How to exploit this flexibility by optimal production planning?
- How to bring flexibility on the energy market?
Our methodology

How to exploit electrical flexibility in industrial sites?
Three different time scales

Hence, decompose in three steps:

- Long-term: workers shifts, approximate production plan
- Medium-term: production plan
- Short-term: adapt production plan

Focus on long-term planning
  - Further split into production and HR

More HR flexibility

Better price predictions
How do we exploit flexibility?

- Long term: two subproblems
  - First, production: when are workers required? → HR is a cost
  - Second, HR: who works when? → Well-being-related constraints
  - Horizon: limited by electricity price prediction
How do we deal with the long-term planning?
Production model

Goals:
• Estimate a production planning
• Determine when workers are needed
Production model

Determine a production planning

- Orders
- Processes
- Electricity prices

Approximate plant model

- Workers shifts
- Production planning
Production model

Determine a production planning

• Horizon?
  • Long enough to have a significant order book
  • Small enough to have good price predictions

• What about HR considerations?
  • Workers are “just” a cost
    • Roughly 1000€ for a team during one hour
  • No specific constraint for well-being
Which level of details for the plant?

- A rough model is enough
  - Except if a process is not well approximated

- The details are for the short-term optimisation

<table>
<thead>
<tr>
<th>Rough model</th>
<th>Fine model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Any process lasts 1 h</td>
<td>Some processes take 30 min, others 45 min</td>
</tr>
<tr>
<td>Consumption is constant with production, fixed batch size</td>
<td>Consumption is linear, quadratic...</td>
</tr>
<tr>
<td>Some stages are ignored</td>
<td>All stations are included</td>
</tr>
<tr>
<td>No wait time between processes</td>
<td>Wait time can be optimised</td>
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Rough model

- Any process lasts 1 h
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- Some stages are ignored
- No wait time between processes

Fine model

- Some processes take 30 min, others 45 min
- Consumption is linear, quadratic...
- All stations are included
- Wait time can be optimised
HR model

Goal: assign shift to worker teams
Respect legal and well-being constraints
HR model

Assign teams to shifts

Shift workers must have some rest between two shifts
HR model

Assign teams to shifts

Shift workers also need a WE, i.e. a pair of days off every so often
HR model

Assign teams to shifts

Shift workers should work no more than 50 hours per week

- Otherwise, overtime
HR model

Assign teams to shifts

- On average, shift workers should work 38 hours per week
  - The average is computed on 13 weeks
- Hard to implement:
  - Production schedule for two weeks
  - Constraint for 13 weeks
HR model

Assign teams to shifts

• Legal, HR-related constraints
  • Minimum rest time between two work periods
  • Week-end equivalent for shift work
  • Maximum 50 hours per week (or overtime)
  • Average number of hours per week, computed over 13 weeks (in Belgium)

• Try to accommodate well-being:
  • Warn the workers a few days before about their schedule
  • Avoid changing too often what the workers are said
  • Avoid overtime

Hard constraints

Committed shifts

Penalisation
• Why is the average number of hours a problem?

• Reach an average of hours **over 13 weeks**
  • Can only work on 2 **weeks**!
  • Production plan after one week is already not really reliable...

• Constraint absolutely needed
  • Must keep flexibility for the weeks after
  • Avoid too many days at the beginning
  • Avoid too many days unused at the end
• Use a *heuristic* 2-week budget
  • Try to have at least $X$ hours, at most $Y$ hours
  • Minimise budget violation

• Leaves some freedom for the current 2 weeks
• Keep margin for the weeks to come

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**Budget of hours**
Objective function

- Minimise penalisations:
  - Hours overtime
  - Hours outside budget (below and above)
  - Number of changes against previous solution

- Each one has a different weight
  - Easy to get multiple assignments
Evaluation

Three axes:
• Computation times
• Monetary gains
• Working conditions
These problems are easy to solve
- 13 weeks, each program with a horizon of 2 weeks
- Mill used 85% of the time
- 5 teams

Production model:
- On average: 0.2s (maximum: 29s)

HR model:
- On average: 0.2s (maximum: 0.3s)

Statistics based on:
- 6 order books
- 18 price scenarios
Monetary gains

Compare this “smart” approach to:

• Two usual industrial scenarios:
  • Produce during the night
  • Produce during the night or the WE

• A softened version of our approach:
  • Cannot reconsider shifts once they are decided

Irrespective of price scenario!
### Monetary gains

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>HR cost</th>
<th>Electricity cost</th>
<th>Total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smart</td>
<td>974,426</td>
<td>752,689</td>
<td>1,727,114</td>
</tr>
<tr>
<td>No change</td>
<td>1,023,973</td>
<td>+ 5.1%</td>
<td>1,928,297</td>
</tr>
<tr>
<td>Night</td>
<td>1,289,920</td>
<td>+ 24.5%</td>
<td>2,269,125</td>
</tr>
<tr>
<td>Night and WE</td>
<td>1,262,530</td>
<td>+ 29.6%</td>
<td>2,288,131</td>
</tr>
</tbody>
</table>

**Bar chart**

- **Electricity**
- **HR**
Working conditions

• Monitor several KPIs:
  • Physiological KPIs
  • Social KPIs
  • Economical KPIs

• Major problems?
  • Scarce literature for flexible shifts
  • Some important notions no more make sense
    • Cycle, rotation, mostly
### Physiological KPIs (14 days)

<table>
<thead>
<tr>
<th>Team</th>
<th>#1</th>
<th>#2</th>
<th>#3</th>
<th>#4</th>
<th>#5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sequence night–rest</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sequence rest–night</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Clockwise transitions (MA, AN, NM)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Counterclockwise transitions (AM, MN, NA)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>No transition (MM, AA, NN)</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Night shifts</td>
<td>2</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Average hours per day</td>
<td>3.4</td>
<td>3.4</td>
<td>4.0</td>
<td>3.4</td>
<td>3.4</td>
</tr>
</tbody>
</table>

### Social KPIs (14 days)

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<tbody>
<tr>
<td>Morning shifts</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>WE shifts</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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### Economical KPIs (14 days)

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<th>#4</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Total shifts</td>
<td>6</td>
<td>6</td>
<td>7</td>
<td>6</td>
<td>6</td>
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<tr>
<td>Diff. with max (%)</td>
<td>14.2857</td>
<td>14.2857</td>
<td>0.</td>
<td>14.2857</td>
<td>14.2857</td>
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<tr>
<td>Total wage</td>
<td>6000.</td>
<td>6000.</td>
<td>7000.</td>
<td>6000.</td>
<td>6000.</td>
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<tr>
<td>Diff. with max (%)</td>
<td>14.2857</td>
<td>14.2857</td>
<td>0.</td>
<td>14.2857</td>
<td>14.2857</td>
</tr>
<tr>
<td>Hourly wage</td>
<td>125.</td>
<td>125.</td>
<td>125.</td>
<td>125.</td>
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<td>Average hours per day</td>
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<td>3.4</td>
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<td>2.9</td>
<td>1.7</td>
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<td>3</td>
<td>1</td>
</tr>
<tr>
<td>WE shifts</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Shift estimate changes: come</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>(at most 7 days before)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shift estimate changes: do not come</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
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<td>3</td>
</tr>
<tr>
<td>Diff. with max (%)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>16.667</td>
<td>50.</td>
</tr>
<tr>
<td>Total wage</td>
<td>6000</td>
<td>6000</td>
<td>6000</td>
<td>5000</td>
<td>3000</td>
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<tr>
<td>Diff. with max (%)</td>
<td>0</td>
<td>0</td>
<td>0</td>
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Conclusion and future work
Conclusion

- From 19th-century planning to flexibility:
  - Could save 30% in costs!

- Probably not acceptable as such:
  - Complete mentality change
  - Workers and directors not always ready

- Objective elements to foster thinking
Future work: production model

- Some HR flexibility not yet exploited:
  - What about **variable** shift lengths?
  - E.g., if 4 consecutive hours are very cheap

- For now: fixed to 8 hours, distinction between morning/afternoon/night shifts

- Great troubles for HR analysis: even further away into the unknown!

- Price uncertainty not explicitly modelled
Future work: HR model

• Introduce fairness criteria when making teams
  • May have large impact on some KPIs

• Potential performance degradation (cf. attic problem)
• First tests show that the effect on runtime is limited
Questions?