WP5: Electricity optimization
Final Report

ABB Corporate Research Center, Ladenburg, Germany
Acciai Speciali Terni
Imperial College London

31/03/2015
ITN Research Objective 3: Study ways that energy savings can be achieved.

WP5 aims to deliver technology prototypes for energy/cost savings at the scale of production processes:

- By analysing the interaction between large and variable industrial loads and the electrical grid.
- By developing and implementing scheduling optimization methods to integrate the production of a steel plant.
- By developing a framework and methods for demand response of energy-intensive processes.

**ESR-G (Dionysios Xenos)**
6 months @ Imperial

**ESR-L (Dragoljub Gajic)**
25 months @ AST

**ESR-N (Robin Cartoux)**
16 months @ DE-ABB

**ESR-K (Hubert Hadera)**
36 months @ DE-ABB
ESR-K (Hubert) Hadera

- WP5 is mainly built around the steel case study

- For this electricity intensive meltshop process, ESR-K (Hubert Hadera) developed an approach to consider simultaneously energy supply and production scheduling in order to cut electricity costs.

- This approach fits into the more generic framework of industrial demand side management and was also applied to other processes (pulp and paper).
ESR-N (Robin Cartoux)

- ESR-N (Robin Cartoux) addressed the coordination between the meltshop and hot rolling mill process in order to reduce reheating energy consumption.

- Reuse and control existing scheduling systems for meltshop and hot strip mill (MSO and HSO respectively)

- Plant-wide approach to integrate the scheduling across different production areas
ESR-L (Dragoljub Gajic)

- His objective was to develop, test and implement creative solutions for energy (cost) savings in stainless steel industry focusing on melt shop and hot rolling mill area.

- ESR-L (Dragoljub Gajic) deployed and integrated in AST the melt shop scheduling optimization system.

- Integration with other plant IT systems and real-time monitoring.
ESR-G (Dionysios Xenos)

- The optimal operation and maintenance of compressors is studied in WP2.
- The integration of operational and energy aspects involves several steps:

  - Investigation of the electricity suppliers characteristics, constraints and parameters which influence the operation of the compressors.
  - Combination of different time scales, a time horizon of few weeks (maintenance time scale) and a time horizon of few days (variation of electricity prices time scale)
Networking

Tight collaboration between AST and ABB-DE:
• 5 meetings in Terni and 2 in Ladenburg with ESRs and supervisors
• Terni case study report drafted and preliminary approved (to be finished by July 2014)

ITN consortium meetings:
• Consortium Meeting 2012 in Ladenburg with BASF site visit
• Workshop 2013 "Optimization and Energy Savings" in Ladenburg
• Consortium Meeting in September 2014 in Terni with AST stainless steel plant site visit.

2 academic secondments at CMU:
• Feb-May 2013: Continuous time batch scheduling of steel plant with optimization of energy cost, ESR-K (Hubert Hadera)
• Jan-Apr 2014: Theoretical and practical study on mathematical optimization, ESR-L (Dragoljub Gajic)

University supervision:
• ESR-K (Hubert Hadera): PhD candidate at TU Dortmund (Prof. Engell). The degree defence is expected in April/May 2015
• ESR-L (Dragoljub Gajic): PhD candidate at University of Belgrade (Prof. Djurovic). Visiting researcher at University of L’ Aquila (Prof. Di Gennaro). The PhD defence will be held on February 9, 2015.
<table>
<thead>
<tr>
<th>Training</th>
<th>Location</th>
<th>Who</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimization Modeling, Conceptual Design and Integrated Process Operations, optimization short-course</td>
<td>CMU, Pittsburgh (US)</td>
<td>ESR-K (Hubert Hadera), ESR-N (Robin Cartoux), ESR-L (Dragoljub Gajic), ESR-G (Dionysios Xenos)</td>
</tr>
<tr>
<td>Project Planning, Analysis and Control, Project management course</td>
<td>ABB, Baden (Switzerland)</td>
<td>ESR-K (Hubert Hadera)</td>
</tr>
<tr>
<td>Industrial optimization: compact course and challenge workshop, optimization short-course</td>
<td>Heidelberg University (Germany)</td>
<td>ESR-K (Hubert Hadera), ESR-N (Robin Cartoux)</td>
</tr>
<tr>
<td>Power Speech, Seminar on presentation skills</td>
<td>ABB, Ladenburg (Germany)</td>
<td>ESR-K (Hubert Hadera), ESR-N (Robin Cartoux)</td>
</tr>
<tr>
<td>SmartOps Professional Skills Course: Series of mini-courses on soft-skills for researchers</td>
<td>Imperial College, London (UK)</td>
<td>ESR-K (Hubert Hadera), ESR-L (Dragoljub Gajic), ESR-N (Robin Cartoux)</td>
</tr>
<tr>
<td>Technology Brokerage Program: Technology transfer, intellectual property, business plans and project management</td>
<td>Ministry of Education, Science and Technological Development, Belgrade (Serbia)</td>
<td>ESR-L (Dragoljub Gajic)</td>
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<tr>
<td>Project Management Professional (PMP) Certification</td>
<td>Project Management Institute, USA</td>
<td>ESR-L (Dragoljub Gajic)</td>
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<tr>
<td>MSc courses in Process Systems Engineering</td>
<td>Imperial College, London (UK)</td>
<td>ESR-G (Dionysios Xenos)</td>
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<tr>
<td>Introduction courses to C, C# programming languages</td>
<td>Imperial College, London (UK)</td>
<td>ESR-G (Dionysios Xenos), ESR-K (Hubert Hadera)</td>
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## Training

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<tbody>
<tr>
<td>Process simulation and design</td>
<td>Cranfield University (UK)</td>
<td>ESR-G (Dionysios Xenos)</td>
</tr>
<tr>
<td>Specification &amp; Performance of Mechanical &amp; Electrical Rotating Equipment</td>
<td>Cranfield University (UK)</td>
<td>ESR-G (Dionysios Xenos)</td>
</tr>
<tr>
<td>Language courses (German, Italian)</td>
<td>Ladenburg (Germany), Terni (Italy)</td>
<td>ESR-K (Hubert Hadera), ESR-L (Dragoljub Gajic), ESR-N (Robin Cartoux)</td>
</tr>
<tr>
<td>Control &amp; Operation of centrifugal gas compressors</td>
<td>ESD Training (UK)</td>
<td>ESR-G (Dionysios Xenos)</td>
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<tr>
<td>Negotiation Skills course</td>
<td>IMECHE, London (UK)</td>
<td>ESR-K (Hubert Hadera)</td>
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<tr>
<td>Visiting Researcher with Dr. Joakim Ekström</td>
<td>University of Linköping, Campus Norrkoping (Sweden)</td>
<td>ESR-K (Hubert Hadera)</td>
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## Dissemination

### Website and blog

### Publications

<table>
<thead>
<tr>
<th>Type</th>
<th>Title</th>
<th>Place and Date</th>
<th>Status</th>
<th>Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>Journal publication</td>
<td>Improved energy-awareness formulation for Mixed Integer Linear Programing continuous-time scheduling models (working title)</td>
<td>Industrial and Engineering Chemistry Research</td>
<td>Under revision by co-authors (01/2015)</td>
<td>ESR-K (Hubert Hadera)</td>
</tr>
<tr>
<td>Journal publication</td>
<td>Optimization of steel production scheduling with complex time-sensitive electricity cost</td>
<td>Computers and Chemical Engineering</td>
<td>Accepted</td>
<td>ESR-K (Hubert Hadera)</td>
</tr>
<tr>
<td>Journal publication</td>
<td>Integration of production scheduling and energy-cost optimization using Mean Value Cross Decomposition (working title)</td>
<td>Computers and Chemical Engineering</td>
<td>Under revision by co-authors (01/2015)</td>
<td>ESR-K (Hubert Hadera)</td>
</tr>
<tr>
<td>Journal publication</td>
<td>Modeling and optimization of energy-efficient procedures for removing lead(II) and zinc(II) ions from aqueous solutions using the central composite design</td>
<td>Energy</td>
<td>Published</td>
<td>ESR-L (Dragoljub Gajic)</td>
</tr>
<tr>
<td>Conference paper</td>
<td>Continuous-time Batch Scheduling Approach for Optimizing Electricity Consumption Cost</td>
<td>ESCAPE23, Lappeenranta, June ‘13</td>
<td>Published</td>
<td>ESR-K (Hubert Hadera)</td>
</tr>
<tr>
<td>Conference paper</td>
<td>Production scheduling optimization in a melt shop</td>
<td>SDEWES 2014, Bor, Serbia, October ‘14</td>
<td>Published</td>
<td>ESR-L (Dragoljub Gajic)</td>
</tr>
<tr>
<td>Conference paper</td>
<td>Optimization of a bentonite-based heterogeneous system for thermal energy storage</td>
<td>SDEWES 2014, Ohrid, Macedonia, July ‘14</td>
<td>Published</td>
<td>ESR-L (Dragoljub Gajic)</td>
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## Publications (2)

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<tbody>
<tr>
<td>Conference paper</td>
<td>Modelling and optimization of methylene blue adsorption from aqueous solution using bentonite clay</td>
<td>ESCAPE24, Budapest, June ’14</td>
<td>Published</td>
<td>ESR-L (Dragoljub Gajic)</td>
</tr>
<tr>
<td>Conference paper</td>
<td>Key Note Lecture: Steel production scheduling under time-sensitive electricity cost</td>
<td>ESCAPE24, Budapest, June ’14</td>
<td>Published</td>
<td>ESR-K (Hubert Hadera)</td>
</tr>
<tr>
<td>Conference paper</td>
<td>A Cross Decomposition Strategy for Industrial Demand-Side Management of a Pulping Process</td>
<td>ESCAPE25, Copenhagen, June ’15</td>
<td>Accepted</td>
<td>ESR-K (Hubert Hadera)</td>
</tr>
<tr>
<td>Conference talk</td>
<td>Process and Production Optimization for Industrial Applications</td>
<td>SIAM, Boston, March ’13</td>
<td>Published</td>
<td>ESR-K (Hubert Hadera)</td>
</tr>
<tr>
<td>Conference talk</td>
<td>Steel Plant scheduling with optimization of time-sensitive electricity purchases</td>
<td>AIChE, San Francisco, Nov ’13</td>
<td>Published</td>
<td>ESR-K (Hubert Hadera)</td>
</tr>
<tr>
<td>Conference talk</td>
<td>Plant-wide coordination for the energy-efficient scheduling of an integrated steel production process</td>
<td>AIChE, Atlanta, Nov ’14</td>
<td>Published</td>
<td>ESR-N (Robin Cartoux)</td>
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<tr>
<td>Conference talk</td>
<td>A Bi-Level Heuristic for Steel Plant Scheduling Under Complex Time-Sensitive Price Structures</td>
<td>AIChE, Atlanta, Nov ’14</td>
<td>Published</td>
<td>ESR-K (Hubert Hadera)</td>
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<tr>
<td>Poster</td>
<td>ITN poster sessions</td>
<td>Krakow, ‘12 Ladenburg, ’13</td>
<td>Published</td>
<td>ESR-L (Dragoljub Gajic), ESR-K (Hubert Hadera)</td>
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<tr>
<td>Poster</td>
<td>Enterprise-wide optimization in an integrated stainless steel mill</td>
<td>Pittsburgh, March ’14</td>
<td>Published</td>
<td>ESR-L (Dragoljub Gajic)</td>
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<tr>
<td>Poster</td>
<td>Electricity demand-side management in steel plant scheduling</td>
<td>Pittsburgh, March ’13</td>
<td>Published</td>
<td>ESR-K (Hubert Hadera)</td>
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<tr>
<td>Interview</td>
<td>ABB de.inside.com Unicum student magazine</td>
<td>Germany, Jan ’12 Germany, Jan ’12</td>
<td>Published</td>
<td>ESR-K (Hubert Hadera)</td>
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ESR-K (Hubert Hadera)

- The potential impact of intelligent energy-aware scheduling of processes has been evaluated by ESR-K (Hubert Hadera) to a reduction of electricity cost of 2-20%

(See papers and presentations with case study results in the publication list: ESCAPE23, AICHE2013, ESCAPE24)
Impact

- Improvement of the coordination between the meltshop hot rolling area
- Potential to reduce inventory levels and reheating energy consumption, thus reducing natural gas consumption and GHG emissions. Prototype testing showed potential reheating energy savings up to 20%.
ESR-L (Dragoljub Gajic)

- The system deployment has improved coordination between different production stages in the melt shop and thus lowered hold-up times, electricity costs and increased production rate.
- Benefits are estimated to be:
  - Reduction in energy consumption: up to 5%
  - Reduction in lead times: 4-5%
  - Reduction in inventory levels: 2-3%
Achievements

<table>
<thead>
<tr>
<th>INTENDED OUTCOME</th>
<th>METHODOLOGY DEVELOPED</th>
<th>MEASURE OF SUCCESS</th>
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<tbody>
<tr>
<td>Create the means to deal with increasing volatility in production, energy &amp; raw material availability. The key aspect is to ensure seamless integration and availability of data and information across the plant, enabling user interaction and connection to optimization solutions.</td>
<td>Level-2 systems have been integrated and all relevant information can be collected and visualized. Flexible user interfaces linked to optimization enable the possibility to perform planning tasks manually, partly or fully supported by the optimization tools. Data mining applying statistical pattern recognition and signal processing has made it possible to identify maintenance needs more efficiently. Mixed integer linear programming optimization models have been studied to include production scheduling and energy volatility, i.e. availability and price. Continuous and discrete-time scheduling models using various decomposition schemes have been developed, for instance applying mean value cross decomposition.</td>
<td>The use of scheduling optimization improved the coordination between different production stages in the melt shop, lowered the hold-up times and increased the production rate. The potential benefits have been estimated to • 5% reduction in energy consumption, • 4-5% in lead times, • 2-3% in inventory levels. The potential impact of intelligent energy-aware scheduling of processes has been evaluated to enable a reduction of electricity cost of 2-20%. The use of an optimized coordination policy between melt shop and rolling mill reduce thermal losses. The anticipated increase of hot charging ratio is up to +22%</td>
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</table>
Conclusion

- Optimization models deliver energy savings and reduced energy cost
- Promising results, strong track of publications
- Methodology tested in real world application
  - Implementation in the process
  - Test case AST Terni
- Strong collaboration within the WP5
Thank you for the attention