A bi-level heuristic for steel plant scheduling under complex time-sensitive price structures

Hubert Hadera[1,2], Iiro Harjunkoski[1]*, Ignacio E. Grossmann[3], Guido Sand[1], Sebastian Engell[2]

[1]ABB Corporate Research, Wallstadter Str. 59, 68526 Ladenburg, Germany

[2] Technical University of Dortmund, Emil-Figge-Straße 70, 44221 Dortmund, Germany

[3]Carnegie Mellon University, 5000 Forbes Ave., Pittsburgh, PA 15213, USA

*Corresponding author, Email: iiro.harjunkoski@de.abb.com

Demand response of industrial production processes can support the transformation process of today's energy supply systems by enabling an active load management. For energy-intensive industries this can be seen as an opportunity to reduce costs taking advantage of process flexibility. This is especially important in the times of the economic crisis when the energy-intensive industry is facing under-utilization which creates valuable process flexibility. As a new way of operating cost reduction, production plants may enter liberalized time-sensitive energy markets. Under special arrangements with a supplier, a plant may be also obliged to commit to certain electricity consumption levels. These aspects create potential for energy-driven production schedule optimization.

With our work we would like address a continuous-time scheduling problem of a Melt Shop section in a stainless steel plant. The plant is assumed to pursue one day schedule with the goal of satisfying complex production rules, minimizing the earliest task completion time and energy bill. The bill is a subject of time-sensitive complex pricing and load deviation penalties. Multiple hourly-varying contracts, onsite generation plant with special constraints and possibility of selling surplus electricity to the grid is considered in this work.

Although the topic of energy-aware scheduling is gaining attention in the literature, considerations of such complex cost structures within continuous-time batch scheduling framework has not been thoroughly investigated. Recent work introduces volatile electricity markets in scheduling of continuous processes (Castro et al. 2009, Castro et al. 2011, Mitra et al. 2012). In Castro at el. (2013) an RTN approach has been successfully used to deal with single price curve and load deviation problem in a stainless steel plant. However, the solution uses a discrete time approach. For the continuous-time driven models, Hait, A., & Artigues (2011) use CP with MILP formulation to arrive at a heuristic solving detailed scheduling of Electric Arc Furnace stage and human operator availability. In Hadera & Harjunkoski (2013) Melt Shop schedule with regard to a single price and load deviation problem is not tractable in reasonable computational times. Tracking of pre-agreed electricity load profiles has been tackled by Nolde & Morari (2010), however without any price signals. Some more complex pricing tariffs have been reported in Ashok (2006) and Hadera et al. (2014).

To tackle the problem of complex price structures and load deviation we develop a monolithic MILP model utilizing the benefit of exact continuous-time approach. The scheduling model is expanded with energy-awareness using event binaries. The binaries

account for the fact whether a task started/finished at a given time interval that is related to energy pricing problem. Next, having the knowledge concerning electricity consumption, we employ optimization of both energy purchase structure and deviation penalties. Since the resulting formulation gives rise to an intractable problem, here we propose a bi-level heuristic. The upper level is an approximation of the original problem scheduling only a part of the available equipment. In the lower level, the rough solution from the upper level problem is fed and evaluated under certain level of flexibility. The resulting schedule of the entire process is then used to update assignment on the most important Electric Arc Furnace stage. This in turn is used to solve the upper level problem in the next iteration.

The model is tested on various problem instances. The results show that the heuristic helps to find good quality solutions in reasonable time. In addition, we show the benefit of energy-aware scheduling compared to more traditional makespan driven approaches. The main limitation of the model that should be addressed in further work is computational performance for even larger scale instances. Also the deterministic nature of the input data concerning the process disturbances and pricing might be tackled with robust optimization or stochastic programming approaches.

References:

S. Ashok, 2006, Peak-load management in steel plants, App. Energy, vol. 83, no. 5, pp. 413-424

P.M. Castro, I. Harjunkoski and I.E. Grossmann, 2009, New continuous-time scheduling formulation for continuous plants under variable electricity cost, Industrial and Engineering Chemistry Research, vol. 48, no. 14, pp. 6701-6714

P.M. Castro, I. Harjunkoski and I.E Grossmann, 2011, Optimal scheduling of continuous plants with energy constraints, Computers and Chemical Engineering, vol. 35, no. 2, pp. 372-387

P. Castro, L. Sun, I. Harjunkoski, 2013, Resource–Task Network Formulations for Industrial Demand Side Management of a Steel Plant, Ind. Eng. Chem. Res., 52, 36, 13046–13058

H. Hadera, I. Harjunkoski, 2013, Continuous-time Batch Scheduling Approach for Optimizing Electricity Consumption Cost, In: Andrzej Kraslawski and Ilkka Turunen, Editor(s), Computer Aided Chemical Engineering, Elsevier, 32, pp. 403-408

H. Hadera, I. Harjunkoski, I. E Grossmann, G. Sand, S. Engell, 2014, Steel production scheduling optimization under time-sensitive electricity cost, Computer Aided Chemical Engineering, Elsevier, accepted

A. Hait and C. Artigues, 2011, A hybrid CP/MILP method for scheduling with energy costs, European Journal of Industrial Engineering, vol. 5, no. 4, pp. 471-489

S. Mitra, I. E. Grossmann, J. M. Pinto and N. Arora, 2012, Optimal production planning under time-sensitive electricity prices for continuous power-intensive processes, Computers and Chemical Engineering, vol. 38, pp. 171-184

K. Nolde and M. Morari, 2010, Electrical load tracking scheduling of a steel plant, Computers & Chemical Engineering, 34, pp. 1899-1903