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Hierarchical Production Scheduling – A Case Study at Perstorp

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Abstract

Planning and scheduling are functions that have large economic impact in the chemical process industry. For integrated sites with many interconnected production areas, obtaining production schedules that respect all production-related constraints is a complex task. One important issue is the constraints due to disturbances in utilities, such as steam and cooling water. These are often site-wide disturbances that may make it impossible to maintain desired production rates in several production areas at a site. In this study, scheduling at two levels of the functional hierarchy at a site of a world lead chemical industry, Perstorp, is handled. The activities are denoted production scheduling (PS) and detailed production scheduling (DPS). Real data of incoming orders and utility disturbances are used to produce a production schedule and detailed production schedule for one month. The PS and DPS problems are formulated as optimization problems, where production-related constraints such as production rate constraints, inventory limitations, and start-up costs are included. The objective functions of the PS and DPS problems are formulated to reflect the importance of different issues at the site. The procedure aims to show how the hierarchical optimization framework may be used to provide decision support for how to operate the production at a site in order to maximize profit while minimizing the effects of site-wide disturbances.

Keywords: production scheduling, utility disturbances, chemical industry, optimization

1. Introduction

To remain competitive, process industrial companies must continuously improve the operational efficiency and profitability (Bansal et al., 2005). The planning and scheduling activities are thus of great importance for these companies, and the functions can yield both for the nearest future and for decades ahead. Different planning strategies and their importance are described in Stadtler and Kilger (2008). Today, use of optimization for planning and scheduling is uncommon at industrial sites, and the tools are mainly spreadsheet based. Furthermore, disturbances in utilities are often not considered directly together with the planning and scheduling problems. The aim of this study is to use optimization methods for solving scheduling problems at two different levels of the functional hierarchy of a site. The solutions from the upper level (time step of days) will be used as input to the lower level (time step of hours), and the solutions from the lower level will in turn be used as feedback for the upper level. A general version of this hierarchical structure has been suggested previously in Lindholm (2013). In the current study, the structure is utilized to perform an industrial case study. To our knowledge, this is the first real industrial case study that is performed using this model structure. A similar two-level planning case study at an oil refinery can be found in

Zondervan et al. (2011). The models in the current study have been constructed using information on site structure, production and inventory limitations, utility usage, etc. from the industrial site. Simulation results for one month are produced with real input data, and are compared to actual plant operation during the same time period. The case study is performed at a site in Stenungsund, Sweden, that is operated by Perstorp. Perstorp produces chemical intermediates such as aldehydes and organic acids, which are delivered to industrial customers to be added to other products used in daily life, for example protective glass and windscreens in cars.

2. Problem description

In the case study, eight products at site Stenungsund that are produced in different production areas are considered, where each area has a separate inventory tank. The interconnection of the production areas and the inventories is shown in Figure 1. In this study, scheduling at two levels of the functional hierarchy at site Stenungsund is handled. The activities are denoted production scheduling (PS) and detailed production scheduling (DPS), in line with the definition in the standard ISA-95 (2005). The hierarchical structure for production scheduling that is presented in Lindholm (2013) is used. A brief description of the structure is given below.

2.1. Hierarchical scheduling

The PS activity produces a production schedule for one month ahead, that suggests how much to produce and sell of each product each day of the month, and how the inventories of the products at the site should be used. The PS activity aims to maximize profit, by minimizing the backlog of orders while considering production and inventory limitations. The schedule is updated each day in receding horizon, based on incoming orders and the actual production the previous day. The production schedule serves as a reference for the DPS activity, which produces a detailed production schedule for one day ahead. The DPS activity determines how the production should be controlled to handle disturbances on a time-scale of hours in an economically optimal way. In the current case study, the response to disturbances in the steam utility is studied. Steam is used by several of the production areas at site Stenungsund and disruptions in the steam supply thus give rise to site-wide disturbances. The detailed production schedule consists of trajectories that suggest how much to produce and sell each hour during the day, and how the buffer tanks at the site should be utilized. The schedule is updated each hour in receding horizon, based on predictions of the operation of the steam utility.

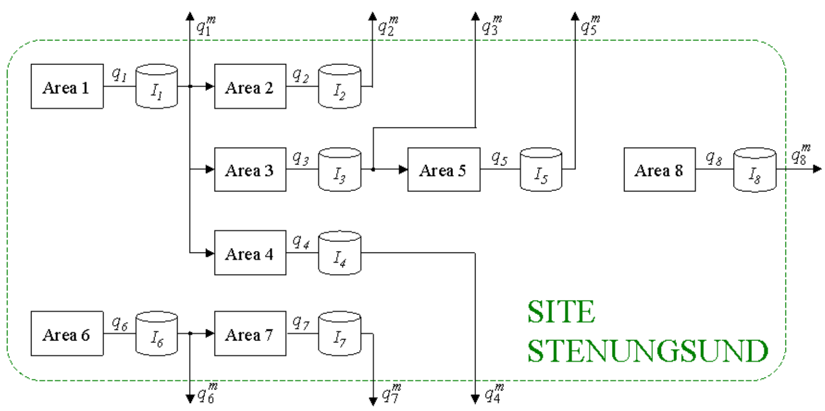

Figure 1. Product flow at site Stenungsund.

2.2. Model inputs and simulation parameters

In the case study, real data from two months during the previous year are used to produce production schedules and detailed production schedules for one month. Data used as input to the models are information on order quantities (i.e. the amount of each product that should be delivered from the site each day), and utility disturbance data (i.e. steam pressure of high and middle pressure steam). Furthermore, information about production-related constraints such as production rate constraints, inventory limitations, and start-up costs is gathered from the site to adapt the models for the PS and DPS. The objective functions of the PS and DPS are formulated to reflect the importance of different issues at the site.

3. Models

The models for the PS and DPS problems consist of constraints related to production, sales, and inventory limitations, and objective functions that aim to maximize the overall profit. Examples of constraints are the limitations due to maximum- and minimum production rates, inventory limitations and limitations due to start-up and shutdown of areas. There are also limitations due to utility disturbances. A simple model of utilities that was presented in Lindholm (2013) is used, that assumes a linear relationship between the amount of a utility that is available and the achievable production rates in the areas that use the utility. The constraints that make the scheduling problem complex are the mass balance constraints and the utility constraints, since these constraints define connections between different areas at the site. Areas are connected both by the flow of products through the site, and by sharing of utilities.

The objective functions of the PS and DPS problems reflect the trade-off between different issues at the site, such as minimizing late delivery of products, keeping the level of the inventories between reference intervals, minimizing variations in production rate, and avoiding shutdown and start-up of areas. For the DPS problem, it also has to be considered how important it is to follow the reference values for sales, production rates, and inventories that are given by the PS, in comparison to avoiding shutdowns and avoiding to change the production rate rapidly. A linear objective function is used for the PS, and a quadratic objective function for the DPS. The full models with all parameters and variables cannot be printed here due to space limitations, but can be found in Lindholm (2013).

4. Results and discussion

The scenario that is studied is the operation of the eight areas at site Stenungsund during one month the previous year. Real input data have been used both for the incoming orders and utility disturbances. The optimization for the PS level is performed each day in receding horizon with a horizon of one month, and the optimization for the DPS level is performed each hour in receding horizon with a horizon of one day. This means that for each optimization, input data (orders and utility disturbance trajectories) for one month/day ahead are needed. In the simulation, the DPS solution is given as feedback to the PS each day. The real data for sales, production rates and inventory usage are only used as initial conditions for the simulation. The utilities that are studied are middle-pressure (MP) steam and high-pressure (HP) steam, where there has been one major disturbance for each of them at day 17 of the month. During this day, MP steam operated at approximately 30 % of its maximum capacity for about 3 h, and HP steam operated at approximately 40 % of its maximum capacity for about 3 h. MP steam is required at areas 1, 2, 3, 4, 6 and 8, and HP steam is required only at area 1.In addition to the utility disturbances, there has also been a planned production disruption during the month. This is a planned shutdown of area 7 at day 11 for 20 h, which is also simulated.

Given the input data and the PS and DPS models according to Lindholm (2013), the hierarchical scheduling is performed for the eight areas at site Stenungsund. The resulting sales, production, and inventory trajectories after one month are shown in Figure 2-4. The notation can be found in Figure 1. As can be seen in Figure 2-4, the suggested sales, production and inventory trajectories given by the PS and DPS are similar to the actual operation of the site during the month, even if no feedback from the measurement data is performed during the simulation. The DPS solution follows the reference values from the PS very closely, which is why the PS solution is rarely visible in the figures. In Figure 2 it can be seen that the ordered volumes of each product are delivered on time most days, even in the presence of disturbances. If the ordered volumes are not delivered on time, they are delivered one or a few days later. In Figure 3 it can be seen that the available HP and MP steam is divided among the areas that require the utilities at the disturbance, day 17. All areas require steam except for area 5, but this area is also indirectly affected due to the area interconnections. Area 2, 3, 4, and 8 are run at the minimum rate during the disturbance, to avoid the high cost of shutting areas down. Area 1 is prioritized during the disturbance since this area provides raw material for several other areas in the network, and area 7 is prioritized because this is one of the most profitable products at the site.

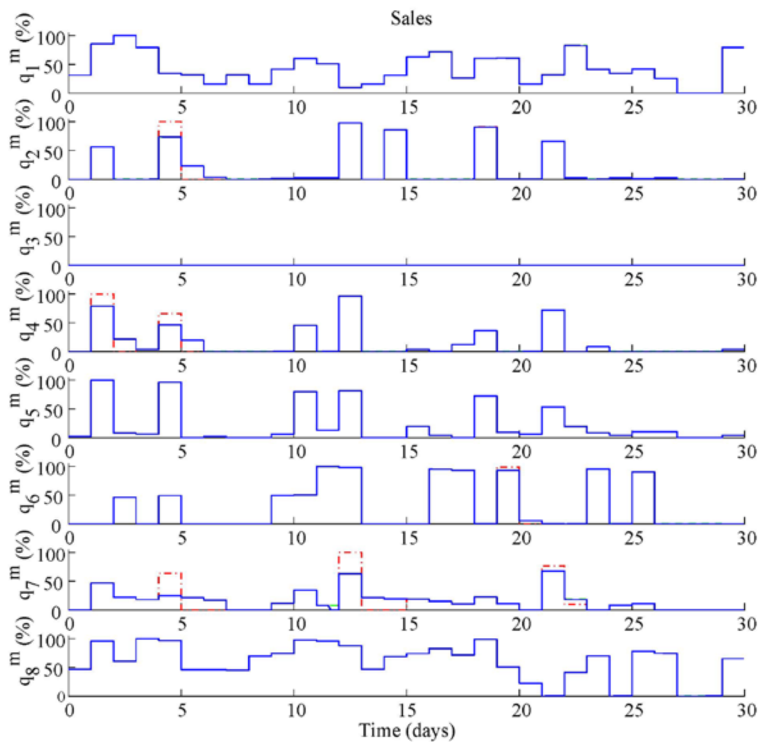

Figure 2. Sales during the month. The red dash-dotted lines mark the ordered volumes, the green dashed lines the PS solution and the blue solid lines the DPS solution.

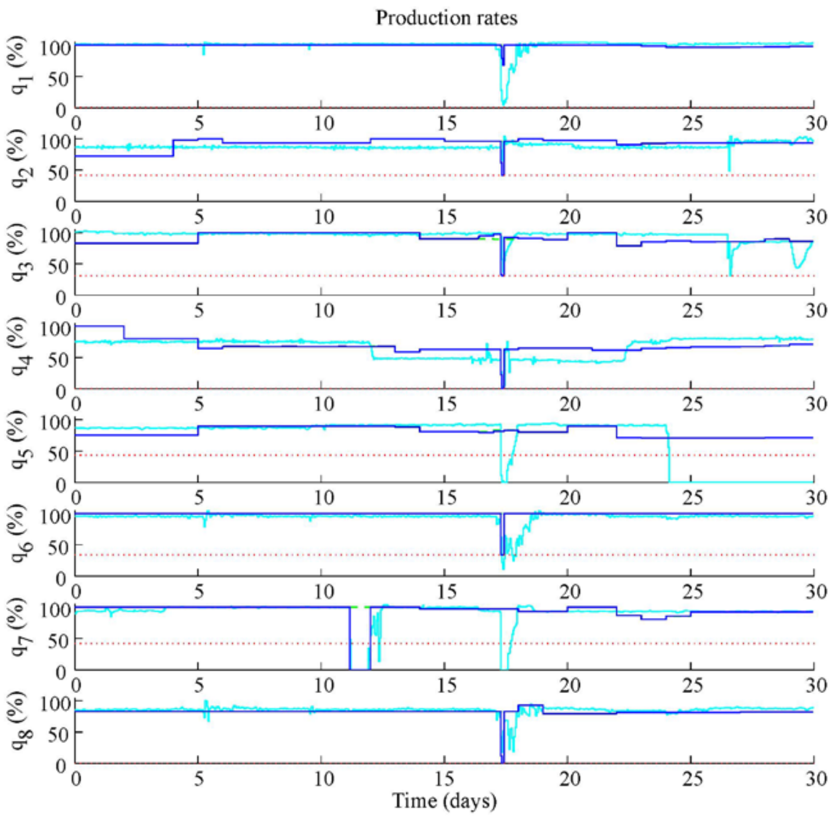

Figure 3. Production rates during the month. The green dashed lines mark the PS solution and the blue solid lines the DPS solution. The actual production rates are plotted in cyan in the same figure. Red dotted lines indicate the minimum production rates.

During the planned production disturbance at day 11, area 7 is forced being shut down. Since the start-up time of this area is 0 days, it can start up again directly after the disturbance. Figure 4 shows that the inventory usage according to the simulation is similar to the actual usage. The inventories are utilized to deliver orders on time and at the same time avoid changing the production rates rapidly. The levels are maintained within the reference intervals when possible, but when needed, they are allowed to deviate outside these intervals.

In the real data in Figures 2-4 it can be seen that the correspondence of the production rates and sales to the change of inventory does not always seem to be perfect for all products at all times. The reason for differences could be e.g. that there are other inventories or product flows of the same products that are not included in the measurements available to us. This indicates that the comparison of the real and simulated trajectories has to be taken with a grain of salt. A more thorough look at the measurement data together with Perstorp would probably make it possible to give a more fair comparison of the trajectories. Nevertheless, we believe that including the measurement data in the figures give some intuition on how well the model captures reality. When performing the scheduling online, this is not a problem since measurements are given as feedback to the DPS level.

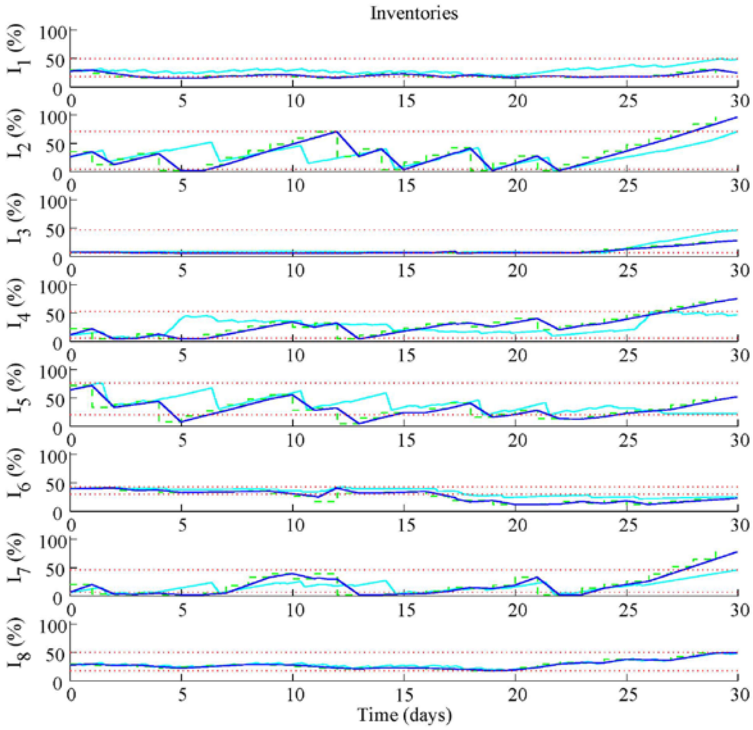

Figure 4. Inventory usage during the month. The green dashed lines mark the PS solution and the blue solid lines the DPS solution. The actual inventory usage is plotted in cyan in the same figure. Red dotted lines mark the reference intervals.

5. Conclusions

The presented case study shows that the suggested hierarchical scheduling procedure may be used as decision support for how to control the production at industrial sites at the occurrence of utility disturbances, or at planned production disturbances. Simulation results imply that the procedure should work well for monthly and daily production scheduling, using the hierarchical structure that is suggested.

Acknowledgement

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