Hierarchical production scheduling in the process industry

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1. INTRODUCTION

The chemical industry has during the past decades become a global marketplace with strong competition between manufacturers, which motivates the need for optimizing the operational efficiency. Planning, scheduling, and control are key features that have large economic impact on process industry operations. In this study, scheduling at two levels of the functional hierarchy of an enterprise are handled. The activities are are denoted *production scheduling* (PS) and *detailed production scheduling* (DPS), in line with the definition in ISA-95.00.03 (2005). The PS operates on a horizon of one month, and the DPS on a horizon of one day. The activities are sometimes denoted *scheduling* and *advanced control* by other authors. The focus is on production scheduling for chemical process industries with continuous production. These sites are often *integrated sites*, where the product produced in one production area may be the raw material to one or more other production areas at the site. An example of an integrated site is given in Fig. 1.

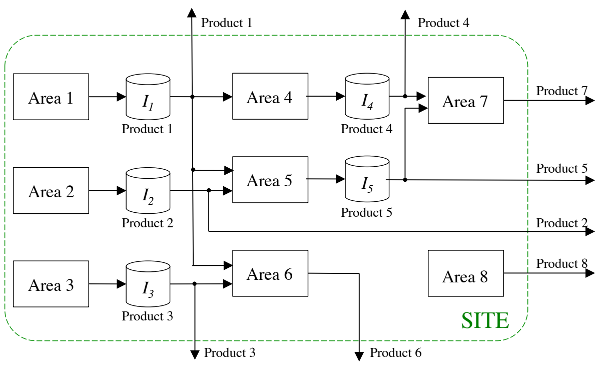

Fig. 1. An example of an integrated site.

Perstorp is a world-leading company within several sectors of the specialty chemical market. The company has 10 production sites around the world, where each production site is divided into about 5-10 production areas. The sites typically run in a continuous mode, without any product changes or grade changes. The aim of Perstorp is to run its sites in a well-defined way even when there are site-wide disturbances such as disruptions in a utility or raw material. In order to do so, decision makers at Perstorp have generated a specification list containing demands and desires for the production scheduling. This list is used as a starting point for finding models for the PS and DPS that are generic enough to be applied to all its sites.

2. SUGGESTED SCHEDULING HIERARCHY

The purpose of the PS activity is to produce a production schedule. The production schedule suggests how much to produce of each product at each area at a specific site each day, and how the inventories of the products at the site should be used. The purpose when making the production schedule is to maximize profit, by minimizing the backlog of orders while considering production and inventory limitations. The suggestion is that the PS activity produces a production schedule one month ahead and updates the plan every day. This time step and horizon has been suggested after discussions with Perstorp. The information needed for making the production schedule can for example be different kinds of capacity, levels of storage for different products, incoming orders, planned maintenance and transports.

The DPS activity should produce a detailed production schedule, that determines how the production should be controlled to handle disturbances on a time-scale of hours in an economically optimal way. 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 suggestion is that this activity operates on a horizon of one day, and updates the schedule every hour. The inputs to the DPS are reference levels for the production, sales, and inventories of all products. Predicted disturbance trajectories are also needed, which may be updated every hour, if needed.

In this study, a two-level approach for integrating PS and DPS is suggested, as shown in Fig. 2. This structure was first introduced in Lindholm et al. (2013), and is based on the scheduling hierarchy presented in ISA-95.00.03 (2005). In the PS layer, a production schedule is set that serves as a reference for the DPS. To produce the schedule, information about the current resource limitations at the site are acquired from the upper level in the hierarchy, 'Business and production planning'. The DPS activity gets its reference values for the production, sales, and inventory levels from the production schedule at the beginning of each day. This activity has an interface to the actual site, where the schedule is executed. This could be done e.g. by the operators at the site or using model-predictive control (MPC). Measurements from the site report to the DPS layer how the production was actually conducted each hour. The site also provides predicted disturbance trajectories that are used to produce the detailed production

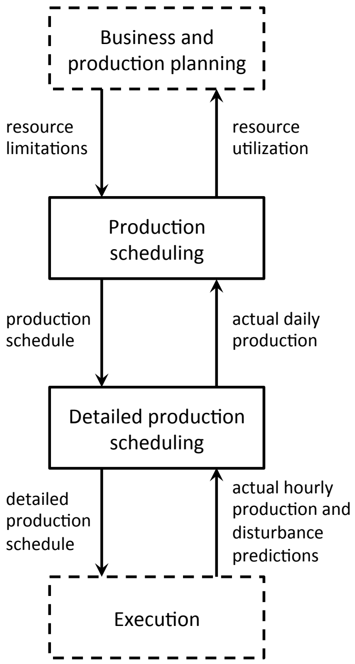

Fig. 2. Suggested structure for scheduling and utility disturbance management.

schedule. The information on the actual production and inventory usage is aggregated and reported to the PS activity at the end of each day. The resource utilization given the production schedule is reported back to the business and production planning level. Our suggestion is to run both the PS and DPS in receding horizon, and produce a new schedule in every time step, but an alternative would be to redo the schedule only when needed, as in Kadam and Marquardt (2007).

3. SCHEDULING SPECIFICATIONS

Together with Perstorp, a list of specifications for the PS and DPS activities was produced. Some key features that have to be handled by the scheduling activities are the connection of production areas at the site, production rate and inventory limitations, start-up costs, cost of production rate changes, market conditions, and constraints due to utilities such as steam and cooling water. Of course, the specification list can be made very long if much details and special cases are taken into account, but in this study it has been chosen to only include the specifications that were deemed to be most important by Perstorp.

4. MATHEMATICAL FORMULATION OF THE SCHEDULING PROBLEMS

The specifications for the PS and DPS activities may be incorporated into two optimization problems, one for the PS that is solved once every day of the month, and one for the DPS that is solved once every hour of the day. Equality and inequality constraints ensure that the mass balance, production rate, and inventory limitations are fulfilled, and the objective functions aim to balance the costs and profits for the PS and DPS activities. The formulation that is suggested in this study results in a mixed-integer linear program (MILP) for the PS problem and a mixed-integer quadratic program (MIQP) for the DPS problem.

5. RESULTS

The scheduling can be simulated using the suggested models for the PS and DPS problems. For example, the reaction to different utility disturbances, such as a pressure drop in the steam net or an electricity failure, may be studied. The results from these simulations may be used for proactive disturbance management for typical utility disturbances. The PS and DPS can also be performed online using measurements from the actual site, and act as decision support for reactive disturbance management at the occurrence of a utility disturbance, or a disturbance in the incoming orders.

6. CONCLUSIONS AND FUTURE WORK

A hierarchical approach for integrating production scheduling (PS) and detailed production scheduling (DPS) is presented, which aims to be general; such that it can be used at any process industrial site. A specification list from Perstorp is used as a starting point for formulating the two scheduling problems, and the interaction and flow of information between the problems is described. The PS problem becomes a mixed-integer linear program (MILP) and the DPS problem a mixed-integer quadratic program (MIQP). Both problems are solved in receding horizon fashion, the PS problem with a horizon of one month, and the DPS problem with a horizon of one day.

The PS model is currently further developed at Linköping University, Sweden. The aim is to take more aspects of the PS into account to make the model more realistic. Another interesting future work direction would be to solve the monolithic scheduling problem, where the PS and DPS problems are merged into one problem, and compare this truly optimal solution to the solution when using the hierarchical scheduling approach.

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