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Production scheduling of a large-scale industrial continuous plant: Short-term and medium-term scheduling

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ABSTRACT

In this work, we describe a framework for short-term and medium-term scheduling of a large-scale industrial continuous plant. For medium-term scheduling, two sub-problems are solved using a rolling-horizon based decomposition scheme. An upper-level model is used to find the optimal number of products, and the length of the time horizon to be considered for solving the lower level short-term scheduling problem. At the lower level, we proposed an improved model for short-term scheduling of continuous processes using unit-specific event-based continuous-time representation. The proposed formulation is demonstrated on a large-scale industrial case study comprising up to 100 units with 1/3 processing and 2/3 storage units operating in a continuous-mode for producing more than 100 different products over a one month time horizon.

1. Introduction

The short-term and medium-term scheduling problem of continuous plants has drawn less consideration in the literature compared to that of batch plants, although continuous units are prevalent in the chemical process industries. In medium-term scheduling relatively longer time horizons of several weeks are considered, while short-term scheduling deals with shorter time horizons of the order of several hours to days. The medium-term scheduling problem is more difficult to solve, and hence, it invariably involves decomposition schemes in practice (Dimitriadis, Shah, & Pantelides, 1997; Lin, Floudas, Modi, & Juhasz, 2002), especially for large-scale industrial problems (Janak, Floudas, Kallrath, & Vormbrock, 2006a, 2006b)

In this work, we present a novel approach for the short-term and medium-term scheduling of large-scale industrial continuous plants. For medium-term scheduling, a rolling-horizon based decomposition scheme (Lin et al., 2002; Janak et al., 2006a) is used and two sub-problems are solved. At the upper-level, a variant of the model proposed by Lin et al. (2002) and Janak et al. (2006a) is used to find the optimal number of products, and the length of the time horizon to be considered for solving the short-term scheduling problem at the lower level. At the lower level, we propose an extension of the model of Shaik and Floudas (2007) for short-term scheduling of continuous processes using unit-specific event-based continuous-time representation (Ierapetritou & Floudas, 1998a, 1998b; Ierapetritou, Hene, & Floudas, 1999; Lin & Floudas, 2001; Lin et al., 2002; Lin, Janak, & Floudas, 2004; Floudas & Lin, 2004, 2005; Janak, Lin, & Floudas, 2004, 2005; Janak et al., 2006a, 2006b; Janak, Lin, & Floudas, 2007; Janak & Floudas, 2008; Shaik, Janak, & Floudas, 2006; Shaik & Floudas, 2007, 2008). A comparative study of different continuous-time models for short-term scheduling of batch plants can be found in Shaik et al. (2006). Ierapetritou and Floudas (1998b) had proposed an approximation of the storage task timings for handling different storage requirements for short-term scheduling of continuous plants. Shaik and Floudas (2007) extended their model in order to precisely handle the different storage requirements. Their formulation is based on the state-task-network representation (STN) resulting in a mixed-integer linear programming (MILP) model that accurately accounts for various storage requirements such as dedicated, flexible, finite, unlimited and no-intermediate-storage policies. The formulation allows for unit-dependent variable processing rates, sequence-dependent changeovers and with/without the option of

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Nomenclature

Initial Priority Assignment Problem:

Indices u units
s, s' states
Sets M main units
S^{art} states that are articles with final demand
Parameters $P_{s,u}$ priority of the suitable main unit u for each article s (=1,first priority; = 2, second priority)
$Mt_{s,u}$ processing time required for each article s on suitable main unit u
$P_u^{\min}$ lower bound on percentage utilization for main unit u
$P_u^{\max}$ upper bound on percentage utilization for main unit u
Th length of the overall time horizon ($Th = 744$ h)
C_k cost coefficients in the objective function
Binary variable $Y(s,u)$ if article s is assigned to main unit u

Level-1 Decomposition Model:

Indices t,d sub-horizons
i tasks
Sets D sub-horizons
I_u tasks suitable in unit u
S^{MTO} states that are MTO articles
S^{MTS} states that are MTS articles
S^{tr} states that are truck filled articles
Parameters D^{f} the previous horizon up to which solution is already obtained
$Dem_{s,d}$ amount of article s due on horizon d
$prod_{s,d}$ amount of article s that starts production on horizon d to meet demands on time
$SS_{s',s}$ parameter relating all states s corresponding to an article s'
$TS_{s,i}$ parameter relating all tasks i associated with an article s
$N^{\max}$ maximum number of event points to be considered at Level-2
$upper$ upper limit on the number of binary variables to be considered at Level-2
$lower_u$ lower limit on the utilization of main units at Level-1
$D^{\max}$ upper limit on the number of sub-horizons to be selected at Level-1
$Mts_{s,M,d}$ processing time required on main units for article s due on sub-horizon d
fix_u if a main unit shares articles with other main units (=1, does not share; = 0 shares)
Binary variables $day1(d)$ if horizon d is selected at Level-1
$pprod(s)$ if state s is selected at Level-1
Positive variables $prday(s,d)$ bilinear term for the product of $pprod(s)$ and $day1(d)$
$amt(s,d)$ fraction of the total demand of article s selected in horizon d
$nbin$ number of binary variables
$slbin$ slack on number of binary variables
$subin$ surplus over number of binary variables
$sllow(M)$ slack on minimum utilization of main units
$sulow(M)$ surplus over minimum utilization of main units
Free variable $Obj1$ objective function at Level-1

Level-2 Short-Term Scheduling Model:

Indices i, i', i'' tasks
u, u' units
s, s' states
n, n', n'' events
Sets $U1$ all units corresponding to the states selected by Level-1
U^1 product storage units that are connected to the truck filling unit
U^2 product storage units connected to bag and big bag packing units
FT feed supply units
FS feed storage units
PS product storage units
PF product packing units
S2 states considered at Level-2
S^{bp} base stock states
S^{bptr} base stock states which are refilled by trucks
S^{fs} feed storage states
S^{M} states produced by tasks in main units
S^{ps} product storage states