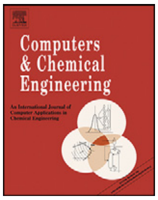
Computers and Chemical Engineering 37 (2012) 214–226

Contents lists available at SciVerse ScienceDirect

Computers and Chemical Engineering

journal homepage: www.elsevier.com/locate/compchemeng



Integrated production planning and scheduling optimization of multisite, multiproduct process industry

Nikisha K. Shah, Marianthi G. Ierapetritou*

Department of Chemical and Biochemical Engineering, Rutgers University, 98 Brett Road, Piscataway, NJ 08854, USA

ARTICLE INFO

Article history:
Received 10 May 2011
Accepted 30 August 2011
Available online 7 September 2011

Keywords:
Planning and scheduling integration
Multisite production
Continuous time formulation
Decomposition method
Augmented Lagrangian relaxation

ABSTRACT

The current manufacturing environment for process industry has changed from a traditional single-site, single market to a more integrated global production mode where multiple sites are serving a global market. In this paper, the integrated planning and scheduling problem for the multisite, multiproduct batch plants is considered. The major challenge for addressing this problem is that the corresponding optimization problem becomes computationally intractable as the number of production sites, markets, and products increases in the supply chain network. To effectively deal with the increasing complexity, the block angular structure of the constraints matrix is exploited by relaxing the inventory constraints between adjoining time periods using the augmented Lagrangian decomposition method. To resolve the issues of non-separable cross-product terms in the augmented Lagrangian function, we apply diagonal approximation method. Several examples have been studied to demonstrate that the proposed approach yields significant computational savings compared to the full-scale integrated model.

1. Introduction

Modern process industries operate as a large integrated complex that involve multiproduct, multipurpose, and multisite production facilities serving a global market. The process industries supply chain is composed of production facilities and distribution centers, where the final products are transported from the production facilities to distribution centers and then to retailers to satisfy the customers demand. In current global market, spatially distributed production facilities across various geographical locations can no longer be regarded as independent from each other and interactions between the manufacturing sites and the distribution centers should be taken into account when making decisions. In this context, the issues of enterprise planning and coordination across production plants and distribution facilities are important for robust response to global demand and to maintain business competitiveness, sustainability, and growth (Papageorgiou, 2009). As the pressure to reduce the costs and inventories increases, centralized approaches have become the main policies to address supply chain optimization. An excellent overview of the enterprise-wide optimization (EWO) and the challenges related to process industry supply chain is highlighted by Grossmann (2005). Varma, Reklaitis, Blau, and Pekny (2007) described the main concepts of EWO and presented the potential research opportunities in addressing the problem of EWO models and solution approaches.

Supply chain optimization can be considered an equivalent term for describing the enterprise-wide optimization (Shapiro, 2001) although supply chain optimization places more emphasis on logistics and distribution, whereas enterprise-wide optimization is aimed at manufacturing facilities optimization. Key issues and challenges faced by process industry supply chain are highlighted by Shah (2004, 2005). Traditional supply chain management planning decisions can be divided into three levels: strategic (long-term), tactical (medium-term), and operational (short-term). The long-term planning determines the infrastructure (e.g. facility location, transportation network). The medium-term planning covers a time horizon between few months to a year and is concerned with decisions such as production, inventory, and distribution profiles. Finally, short-term planning decision deals with issues such as assignment of tasks to units and sequencing of tasks in each unit. The short-term planning level covers time horizon between days to a few weeks and at production level, is typically refer to as scheduling. Wassick (2009) proposed a planning and scheduling model based on resource task network for an integrated chemical complex. He considered the enterprise-wide optimization of the liquid waste treatment network with their model. Kreipl and Pinedo (2004) discussed issues present in modeling the planning and scheduling decisions for supply chain management. For a multisite facilities, the size and level of interdependences between these sites present unique challenges to the integrated tactical production planning and day-to-day scheduling

---

* Corresponding author. Tel.: +1 732 445 2971; fax: +1 732 445 2421.
E-mail address: marianth@rutgers.edu (M.G. Ierapetritou).

0098-1354/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.compchemeng.2011.08.007

Nomenclature

Indices

i	task
j	units
m	distribution market
n	event point
p	production site
s	material state
t	planning period

Sets

I	tasks
I^p	task that can be performed at site p
I_j^p	tasks that can be performed in unit j at site p
J	units
J^p	units that are located at site p
J_i^p	units that can perform task i at site p
M	distribution markets
N	event points
P_s	sites that can produced final product s
PS	production sites
S	material states
S_f^m	products that can be sold at market m
S_f^p	products that can be produced at site p
T	planning periods

Parameters

$d_s^{p,m}$	unit transport cost of material s from site p to market m
$Dem_s^{m,t}$	demand of product s at market m for period t
$FixCost_i^p$	fixed production cost of task i at site p
h_s^p	holding cost of product s at production site p
$stcap_s^p$	available maximum storage capacity for state s at site p
u_s^m	backorder cost of product s at distribution market m
$v_{i,j,p}^{\min}$, $v_{i,j,p}^{\max}$	minimum and maximum capacity of unit j when processing task i at site p
$VarCost_i^p$	unit variable cost of task i at site p
$\alpha_{i,j}^p$, $\beta_{i,j}^p$	constant, variable term of processing time of task i in unit j at site p
$\rho_{s,i}^{c,p}$, $\rho_{s,i}^{p,p}$	proportion of state s consumed, produced by task i respectively at site p

Variables

$b_{i,j,n}^{p,t}$	amount of material processed by task i in unit j at event point n at site p during period t
$D_s^{p,m,t}$	transportation of product s from site p to market m at period t
$Inv_s^{p,t}$	inventory level of state s at the end of the planning period t for site p
$stin_s^{p,t}$	initial inventory for state s in planning period t
$Tf_{i,j,n}^{p,t}$	finish time of task i in unit j at event point n in site p during period t
$Ts_{i,j,n}^{p,t}$	start time of task i in unit j at event point n in site p during period t
$U_s^{m,t}$	backorder of product s at market m in planning period t
$wv_{i,j,n}^{p,t}$	binary variable, task i active in unit j at event point n at site s during period t

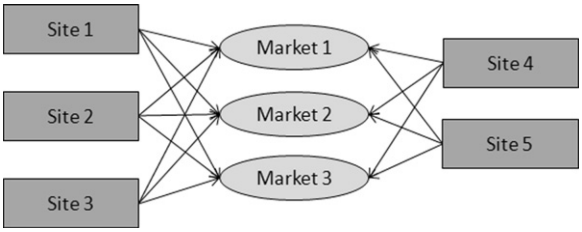


Fig. 1. Multisite production and distribution network.

problem and these challenges are highlighted by Kallrath (2002a). For further elucidation of various aspects of planning, the reader is directed to the work of Timpe and Kallrath (2000) and Kallrath (2002b).

A simple network featuring the multisite facilities is given in Fig. 1, where multiple products may be produced in individual process plants at different locations spread across geographic region and then transported to distribution centers to satisfy customers demand. These multisite plants produce a number of products driven by market demand under operating conditions such as sequence dependent switchovers and resource constraints. Each plant within the enterprise may have different production capacity and costs, different product recipes, and different transportation costs to the markets according to the location of the plants. To maintain economic competitiveness in a global market, interdependences between the different plants, including intermediate products and shared resources need be taken into consideration when making planning decisions. Furthermore, the planning model should take into account not only individual production facilities constraints but also transportation constraints because in addition to minimizing the production cost, it's important to minimize the costs of products transportation from production facilities to the distribution center. Thus, simultaneous planning of all activities from production to distribution stage is important in a multisite process industry supply chain (Shah, 1998).

Wilkinson, Cortier, Shah, and Pantelides (1996) proposed an aggregated planning model based on the resource task network framework developed by Pantelides (1994). Their proposed planning model considers integration of production, inventory, and distribution in multisite facilities. Lin and Chen (2007) developed a multistage, multisite planning model that deals with routings of manufactured products demand among different production plants. They simultaneously combine two different time scales (i.e. monthly and daily) in their formulation by considering varying time buckets. Verderame and Floudas (2009) developed an operational planning model which captures the interactions between production facilities and distribution centers in multisite production facilities network. Their proposed multisite planning with product aggregation model (Multisite-PPDM) incorporates a tight upper bound on the production capacity and transportation cost between production facilities and customers distribution centers in the supply chain network under consideration. A multisite production planning and distribution model is proposed by Jackson and Grossmann (2003) where they utilized nonlinear process models to represent production facilities. They have exploited two different decomposition schemes to solve the large-scale nonlinear model using Lagrangian decomposition. In temporal decomposition, the inventory constraints between adjoining time periods are dualized in order to optimize the entire network for each planning time period. In spatial decomposition technique, interconnection constraints between the sites and markets are dualized in order to optimize each facility individually. They conclude that temporal decomposition technique performs far better than spatial decomposition technique.