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Integration of production planning and scheduling: Overview, challenges and opportunities

Christos T. Maravelias*, Charles Sung

Department of Chemical and Biological Engineering, University of Wisconsin-Madison, 1415 Engineering Dr., Madison, WI, 53706, USA

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ABSTRACT

We review the integration of medium-term production planning and short-term scheduling. We begin with an overview of supply chain management and the associated planning problems. Next, we formally define the production planning problem and explain why integration with scheduling leads to better solutions. We present the major modeling approaches for the integration of scheduling and planning decisions, and discuss the major solution strategies. We close with an account of the challenges and opportunities in this area.

1. Introduction

The supply chain (SC) of a manufacturing company is a network of facilities and distribution options that performs the following functions: procurement of raw materials, transformation of raw material into finished products, and distribution of finished products to customers. The goal is to achieve high customer satisfaction level at low cost (Christopher, 1998; Chopra & Meindl, 2001; Shapiro, 2006). Chemical supply chains in particular contain large opportunities to reduce cost: they are complex interconnected systems that change constantly, and their activities represent a significant portion of total cost to serve customers (Ferrio & Wassick, 2008).

Tayur (2003) noted that inventories in US supply chains can be reduced substantially, without affecting customer satisfaction levels, leading to significant savings. Inventory levels can be reduced if the efficiency of the SC as a whole is improved. Higher efficiency can be achieved through proper coordination of material, financial and information flows across the SC (Grossmann, 2005; Stadtler, 2005; Varma, Reklaitis, Blau, & Pekny, 2007). The planning problems that have to be solved to achieve this coordination cover a wide range of activities, from procurement and production to distribution and sales, and a wide range of time scales from long-term (strategic) to short-term (operational) decisions (Fig. 1).

Strategic (long-term) planning determines the structure of the supply chain (e.g. facility location). Medium-term (tactical) planning is concerned with decisions such as the assignment of production targets to facilities and the transportation from facilities to warehouses to distribution centers. Finally, short-term planning is carried out on a daily or weekly basis to determine the assignment of tasks to units and the sequencing of tasks in each unit. At the production level, short-term planning is referred to as scheduling.

However, due to interconnections between different levels of the supply chain, there are numerous trade-offs between decisions made at the various nodes of the SC. To achieve globally optimal solutions therefore the interdependencies between the different planning functions should be taken into account, and planning decisions should be made simultaneously. In other words, planning problems should be *integrated*.

In this paper, we specifically review approaches for the integration of medium-term production planning and short-term scheduling (Shah, 2005). In Section 2, we review production planning and present the standard lot-sizing formulation that is often used in production planning systems. In the next section, we discuss why integration with scheduling is necessary, review the major approaches to process scheduling, and discuss the implementation of production planning solutions. In Sections 4 and 5, we review the different modeling approaches and discuss the main solution strategies developed to solve the integrated models effectively. We close with a discussion of open challenges in this area and some promising research directions.

* Corresponding author. Tel.: +1 608 265 9026; fax: +1 608 262 5494.
E-mail address: maravelias@wisc.edu (C.T. Maravelias).

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Nomenclature

Indices

$i \in \mathbf{I}$	product (item)
$k \in \mathbf{K}$	resource
$n \in \mathbf{N}$	small-bucket (scheduling) time period of length Δn
$t \in \mathbf{T}$	big-bucket (planning) time period of length Δt

Sets

$\mathbf{D}_i$	set of direct successors of item i
$\mathbf{N}_t$	scheduling time periods in planning period t
$\mathbf{X}_t$	domain of planning variables in period t
$\mathbf{Y}_t$	domain of scheduling variables in period t

Parameters

c_i	setup cost for item i
C_{kt}	capacity of resource k during period t
d_{it}	demand for product i at end of time period t
h_i	holding cost of product i
M_{it}	upper bound on production of item i during period t
p_i	production cost per unit of item i
$r_{ii'}$	amount of item i required to make one unit of successor item $i' \in \mathbf{D}_i$
α_{ik}	capacity requirement of resource k per unit of item i
β_{ik}	capacity requirement of resource k to setup for item i
γ_i	lead time for item i, in units of time periods

Variables

Ch_t	total holding cost in time period t
Cp_t	total production cost in time period t
CT	total overall cost (objective function)
P_{it}	production amount (target) of item i in period t
S_{it}	inventory level of item i at the end of time period t
Y_{it}	=1 if item i is produced in time period t

Functions

$f(P_{it})$	generic function for constraining feasibility of production targets
$g(P_{it})$	generic function for defining cost to meet production targets

2. Production planning

2.1. Problem statement

The objective in production planning is to fulfill customer demand at minimum total (i.e. production + inventory) cost. Formally, we are given:

(i) A planning horizon divided into a set $\mathbf{T}$ of time periods.
(ii) A set $\mathbf{I}$ of products (items) with holding cost h_i, and customer demand d_{it} for product $i \in \mathbf{I}$ due at the end of time period $t \in \mathbf{T}$.
(iii) Resource capacities.
(iv) Production costs.

The optimization decisions include:

(i) Production amount (target) P_{it} of item $i \in \mathbf{I}$ in period $t \in \mathbf{T}$.
(ii) Inventory level S_{it} of item i at the end of period t.

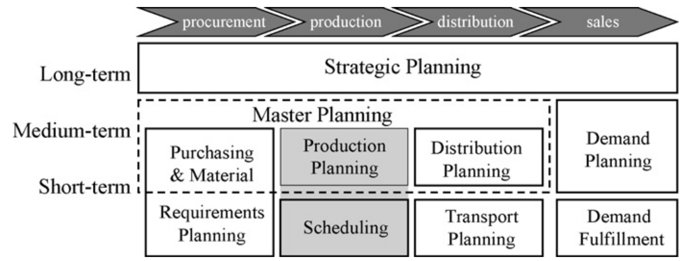

Fig. 1. Supply chain planning matrix (modified from Meyr, Wagner, & Rohde, 2002). We are interested in the integration of medium-term production planning and short-term scheduling (highlighted). See also Fleischmann, Meyr, and Wagner (2002).

If the demand cannot be satisfied in every period, then two variants are considered. In the first one, unsatisfied demand is backlogged and a backlog cost is paid until the backlogged demand is satisfied. In the second one, unsatisfied demand is discarded at cost.

Production planning is often represented as a network problem, with a node for each item and time period, and arcs for the production, demand satisfaction, and inventory (see Fig. 2). The network representation can be extended to include backlog arcs.

2.2. General formulation

If we assume that demand can always be satisfied, then a general formulation for production planning is given in (PP). Feasible production targets are modeled via functions $f(P_{it})$ in Eq. (RC), production cost Cp_t in period t is calculated via function $g(P_{it})$ in (PC), holding cost Ch_t is calculated in Eq. (HC), and the material balance for item i at the end of period t is expressed in Eq. (MB).

$$\begin{aligned}
&\min \quad CT = \sum_{t \in T} (Cp_t + Ch_t) \\
&\text{s.t.} \quad f(P_{it}) \le 0 \quad \forall t \quad \text{(RC)} \\
&Cp_t = g(P_{it}) \quad \forall t \quad \text{(PC)} \\
&Ch_t = \sum_i h_i S_{it} \quad \forall t \quad \text{(HC)} \\
&S_{it} = S_{i,t-1} + P_{it} - d_{it} \quad \forall i, t \quad \text{(MB)} \\
&P_{it}, S_{it} \ge 0 \quad \forall i, t
\end{aligned} \tag{PP}$$

Generic functions $f(P_{it})$ and $g(P_{it})$ depend on the characteristics of the process network and often involve a large number of constraints. The former defines the set of feasible production amounts P_{it}, while the later expresses the production cost as a function of P_{it}. To accurately provide feasibility and production cost information, detailed models with additional variables are used. Among the various production planning methods, their major modeling differences lie in the modeling of resource constraints (RC) and production cost constraints (PC).

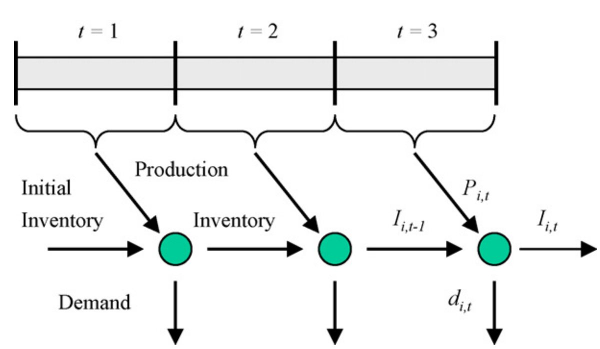

Fig. 2. Flows in production planning (shown here for item i).