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A multiperiod model for production planning and design in a multiproduct batch environment

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ABSTRACT

A general multiperiod model to optimize simultaneously production planning and design decisions applied to multiproduct batch plants is proposed. This model includes deterministic seasonal variations of costs, prices, demands and supplies. The overall problem is formulated as a mixed-integer linear programming model by applying appropriate linearizations of non-linear terms. The performance criterion is to maximize the net present value of the profit, which comprises sales, investment, inventories, waste disposal and resources costs, and a penalty term accounting for late deliveries. A noteworthy feature of this approach is the selection of unit dimensions from the available discrete sizes, following the usual procurement policy in this area. The model simultaneously calculates the plant structure (parallel units in every stage, and allocation of intermediate storage tanks), and unit sizes, as well as the production planning decisions in each period (stocks of both product and raw materials, production plans, policies of sales and procurement, etc.).

1. Introduction

Nowadays, one of the most important challenges faced by business is the adjustment of the firm resources in order to satisfy market requirements subjected to fluctuations over time, mainly costs, prices, existences, demands, etc. In many industries, products have distinctive demand patterns that vary due to market or seasonal changes coupled with raw material supplies that also undergo changes. Because of these variations over time, there has been an increased interest in the development of multiperiod optimization models in recent years.

Flexible production is receiving increased attention in the chemical processing industry. This flexible production leads to faster responses to the market fluctuations and is most commonly achieved in batch plants. In this work, efforts are focused on multiproduct batch production environment, where several different products are produced sharing the same equipment operating in the same sequence.

A batch process refers to a general non-continuous process that consists of multiple stages employing a combination of identical parallel batch units. In a multiproduct batch plant each product is produced at a time. Batch units are characterized by a processing time and no simultaneous feed and removal is performed. Also, intermediate storage tanks may be available between successive stages of operation in order to decouple the production process. Fig. 1 shows a plant configuration of this type of industry.

Most of the previous approaches in batch plants used to pose models that worked with a single long time period and constant conditions without considering variations due to seasonal or market fluctuations. Also, these previous efforts

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Notation

Subscripts

c	Raw material
i	Product
j	Batch stage
m	Number of parallel units at batch stages
s	Discrete sizes for batch stages
t	Time period
v	Discrete sizes for storage tanks

Superscripts

d	Downstream
L	Lower bound
p	Subprocess
u	Upstream
U	Upper bound

Parameters

co_{it}	Operating cost coefficient of product i in period t.
cp_{it}	Cost coefficient for late delivery of product i in period t.
CT	Number of common ingredients for producing each final product i.
DE_{it}	Demand of product i at period t.
F_{cit}	Parameter that accounts conversion of raw material c to produce i at period t.
g_j	Number of discrete sizes available for storage tanks at stage j.
H	Time horizon.
H_t	Net available production time for all products at period t.
k_j	Number of discrete sizes available for batch units at stage j.
np_{it}	Price of product i at period t.
S_{ijt}	Size factor of product i in stage j for each period t.
SI_j	Set of available discrete sizes for the storage tanks allocated after stage j.
ST_{ijt}	Size factor for product i for an intermediate storage tank in the location j.
SV_j	Set of available discrete sizes for the batch units at stage j.
pt_{ijt}	Processing time of product i in batch stage j in period t.
wp_{it}	Waste disposal cost coefficient per product i.
wr_{ct}	Waste disposal cost coefficient per raw material c.
α_j	Cost coefficient for a batch unit in stage j.
β_j	Cost exponent for a batch unit at stage j.
ε_{ct}	Inventory cost coefficient for raw material c in period t.
κ_{ct}	Price for the raw material c in period t.
v_{js}	Standard volume of size s for batch unit at stage j.
π_j	Cost coefficient for an intermediate storage tank allocated in position j.
σ_{it}	Inventory cost coefficient for product i in period t.
τ_j	Cost exponent for an intermediate storage tank allocated in position j.
vt_{jv}	Standard volume of size v for storage tank allocated in position j.
ζ_c	Time periods during which raw materials have to be used.
χ_i	Time periods during which final products have to be used.
Λ_{ij}	Parameter that represents the maximum difference of number of batches.

Binary variables

d_j	It is 1 if the tank is allocated in position j.
st_{jv}	It is 1 if storage at position j has size v.
y_{jm}	It is 1 if batch stage j has m units of the same size in parallel.
z_{js}	It is 1 if equipment at batch stage j has size s.

Integer variables

M_j	Number of parallel units operating out of phase at batch stage j.