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A multiproduct batch plant design model incorporating production planning and scheduling decisions under a multiperiod scenario

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ABSTRACT

In this study, we propose a multiperiod mixed-integer linear programming model, which integrates several decisions related to multistage multiproduct batch plants. In general, plant designs are solved without considering operation decisions, whereas the proposed approach considers production planning as well as scheduling decisions. The time horizon comprises several periods where deterministic variations in prices, product demand limits, costs, and the availability raw materials are considered. The plant operates using different production campaigns throughout each time period. The proposed model allows the optimal plant structure (unit sizes and its duplication in parallel at each stage) to be obtained, as well as the detailed production plan for every time period. Thus, the proposed method allows assessments of the trade-offs between the different decision levels involved by considering fluctuations throughout the time horizon.

1. Introduction

Due to the high flexibility of batch plants in processing facilities, they are the preferred production mode for a large number of chemicals. This production flexibility facilitates faster responses to satisfy market requirements, which are subject to fluctuations over time. However, most previous studies of the optimal design of multiproduct batch plants have utilized models with a single long time horizon and constant conditions, but without considering variations due to market or seasonal fluctuations. These formulations are unsuitable for use in a highly dynamic environment where the problem data vary among periods, so some multiperiod formulations have also been developed.

In addition, most previous studies have focused on a specific decision level. In particular, batch plant design has been solved by considering several assumptions related to planning and scheduling. In general, these assumptions are made to simplify the model formulation and resolution, as well as for use in more typical or normal scenarios. Thus, previous investigations of batch plant design have employed this approach, but a more appropriate problem representation can be developed if the trade-offs among different decision levels can be incorporated, as proposed by Lee et al. [1] for the simultaneous lot-sizing and supplier selection problems, and by Ramezanian and Saidi-Mehrabad [2] for the integrated lot-sizing and scheduling approach.

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Nomenclature

Indices

r	raw materials
i	products
j	stages
k	units
l	slots
m	discrete options for the number of repetition of the campaign
n	number of batches of a product
p	discrete sizes for the units
t, τ	time periods

Parameters

co_{it}	operating cost coefficient of product i in time period t.
cp_{it}	cost coefficient for late delivery of product i in time period t.
DE_{it}^{L}	minimum demand of product i at time period t.
DE_{it}^{U}	maximum demand of product i at time period t.
F_{rit}	conversion of raw material r to produce i at time period t.
H	global time horizon.
H_t	net available production time for all products at time period t.
IM_{r0}	initial inventory of raw material r.
IP_{i0}	initial inventory of product i.
K_j	maximum number of available identical parallel units at batch stage j.
L_{kjt}	number of slots postulated for unit k of stage j during period t.
M_b	big-M constants for $b = 1, 2, 3$.
np_{it}	price of product i at period t.
N_t	number of discrete values proposed by the number of repetitions of the campaign in period t.
NBC_{it}^{U}	maximum number of batches of product i in the campaign of period t.
NN_t^{L}	minimum number of times that the campaign of period t can be repeated.
NN_t^{U}	maximum number of times that the campaign of period t can be repeated.
P_j	number of discrete sizes available for batch stage j.
q_{it}^{L}	lower bound on production level of product i in period t.
q_{it}^{U}	upper bound on production level of product i in period t.
SF_{ijt}	size factor of product i in stage j for each time period t.
pt_{ijt}	processing time of product i in batch stage j in time period t.
T_{mt}	discrete value m for the number of repetitions of the campaign of period t.
VF_{jp}	standard volume of size p for batch unit at stage j.
wp_{it}	waste disposal cost coefficient per product i.
wr_{rt}	waste disposal cost coefficient per raw material r.
α_j	cost coefficient for a batch unit in stage j.
β_j	cost exponent for a batch unit at stage j.
ε_{rt}	inventory cost coefficient for raw material r in time period t.
κ_{rt}	price for the raw material r in time period t.
σ_{it}	inventory cost coefficient for product i in time period t.
ζ_r	time periods during which raw materials have to be used.
χ_i	time periods during which products have to be used.

Binary Variables

d_{mt}	specifies if the campaign is repeated T_{mt} times over time period t.
X_{jklt}	indicates if slot l of unit k at stage j is employed in time period t.
u_{jk}	indicates if unit k of stage j is used.
v_{jp}	specifies if the units at stage j have size p.
x_{int}	denotes if n batches of product i are processed in the campaign of time period t.
Z_{ilt}	indicates if product i is assigned to slot l in time period t.

Continuous Variables

B_{it}	batch size of product i in time period t.
C_{rt}	amount of raw material r purchased in time period t.