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A Mixed Integer Linear Programming model for simultaneous design and scheduling of flowshop plants

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ABSTRACT

Models representing batch plants, especially flowshop facilities where all the products require the same processing sequence, have received much attention in the last decades. In particular, plant design and production scheduling have been addressed as disconnected problems due to the tremendous combinatory complexity associated to their simultaneous optimization. This paper develops a model for both design and scheduling of flowshop batch plants considering mixed product campaign and parallel unit duplication. Thus, a realistic formulation is attained, where industrial and commercial aspects are jointly taken into account. The proposed approach is formulated as a Mixed Integer Linear Programming model that determines the number of units per stages, unit and batch sizes and batch sequencing in each unit in order to fulfill the demand requirements at minimum investment cost. A set of novel constraints is proposed where the number of batches of each product in the campaign is an optimization variable. The approach performance is evaluated through several numerical examples.

1. Introduction

Batch processes are characterized by their flexibility and ability to produce low-volume products, sharing the same equipment. The main classification of batch processes is based on the production path involved for products manufacture: flowshop or multiproduct batch plants are employed when all the products require all the stages following the same sequence of operations, while, in jobshop or multipurpose batch plants, products can follow different processing sequences, not necessarily employing all the stages.

In this paper, the study is focused on flowshop or multiproduct batch plants. The general design problem of this type of facilities consists of determining: (a) the plant configuration, i.e. the number of parallel units required for each stage and, sometimes, the assignment of intermediate storage between stages; (b) the unit and storage vessel sizes; and (c) the number and size of batches for all the products, in order to optimize an economic performance measure while satisfying constraints on the production requirements in the available time horizon. This problem has been generally formulated as a mixed-integer non linear programming (MINLP) model [1].

On the other hand, taking into account that all products, usually with similar recipes, are processed using the same stages, production must be scheduled in order to improve the plant performance and avoid large inventory levels. According to Papageorgiou and Pantelides [2], the campaign mode operation is particularly appropriate for plants working under stable demand patterns over long planning horizons. The plant can be operated with mixed product campaigns (MPC), where in

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Nomenclature

Sets

I	set of products
J	set of stages of batch plant
K_j	set of available identical parallel units in each batch stage j
L	set of production slots
SV_j	set of discrete sizes for stage j

Indices

i	product
j	stage
k	unit
L	slot
n	number of batches of a product
p	discrete size for batch unit
P_j	number of available discrete sizes for a unit of stage j

Parameters

CCF	capital charge factor
CT^{UP}	upper bound for the variable CTC (cycle time)
H	time horizon
NBC_i^{UP}	maximum number of batches of product i in the composition of a campaign
Q_i	demand of product i in the time horizon H
SF_{ij}	size factor of product i in stage j
t_{ij}	processing times for each product i in stage j
VF_{jp}	discrete size for batch units in stage j

Binary variables

v_{jp}	binary variable that denotes if the units of stage j have size p
w_{ijpn}	binary variable that represents the bilinear term $v_{jp}\ X_{in}$
ww_{ijpn}	binary variable that represents the cross product $w_{ijpn}CT$
X_{in}	binary variable that denotes if the campaign has n batches of product i
Y_{ijkl}	binary variable that assigns product i to slot l of unit k in stage j
Z_{jk}	binary variable that specify if unit k of stage j is employed

Continuous variables

B_i	continuous variable that denotes the batch size of product i
CTC	continuous variable that denotes the cycle time of the campaign
CT_{jk}	continuous variable that denotes the cycle time of unit k at stage j
e_{jkp}	continuous variable that represents the bilinear term $Z_{jk}\ v_{jp}$
NBC_i	continuous variable that represents the number of batches of product i included in the campaign
NB_i	continuous variable that represents the total number of batches of product i in the time horizon
NC	continuous variable that represents the number of times that the campaign is repeated
TF_{jkl}	continuous variable that denotes the finishing time of slot l in unit k of stage j
TI_{jkl}	continuous variable that denotes the starting time of slot l in unit k of stage j
V_j	continuous variable that denotes the size of a batch unit in stage j

each campaign various batches of different products are manufactured and the same batches arrangement is cyclically repeated over the time horizon. In this case, several decisions must be made at the scheduling level: the number of batches of each product involved in the production campaign and their sequencing in order to optimize a suitable performance measure. This problem represents an important challenge given the combinatorial nature of scheduling decisions. Most formulations for scheduling belong to the set of NP-complete problems [3] and, despite significant advances in optimization approaches, there is still a number of major challenges and questions that remain unsolved [4]. When the plant design is not a priori provided, the problem becomes worse, because both the number of batches of each product and the available equipment are unknown. In this last case, in order to simplify the model, most of the formulations assume single product campaigns (SPC), where all batches of a given product are manufactured before switching to another product. However, this proposal is not appropriate for the production or commercial points of view.

The multistage nature of a batch plant allows four different storage options: (i) unlimited intermediate storage (UIS); (i) finite intermediate storage (FIS); (iii) no intermediate storage (NIS); (iv) zero wait (ZW). In both the NIS and ZW modes, there