

# A mixed integer linear programming model for simultaneous design and scheduling of flowshop plants

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## Abstract

Batch processes are characterized by flexibility and the ability to produce small amounts of products, specialties with relatively short life cycles, sharing the same equipment. The main classification of batch processes is based on the production path involved for products manufacture: flowshop plants are employed when all products require all the stages following the same sequence of operations, and jobshop plants when not all products follow the same processing sequence.

In this work, the study is focused on flowshop plants. The design problem of such plants consists in determining: (a) plant configuration, i.e. the number of parallel units required for each stage and the assignment of intermediate storage between stages; (b) sizing of the units and storage vessels; and (c) the number and size of batches for all products, so as to minimize the investment cost of the plant while satisfying the constraints on the production requirements in the available time horizon.

From the design point of view, this problem has been generally formulated as a non linear mathematical model (Barbosa-Póvoa, 2007). On the other hand, taking into account that several products are processed using the same units, production must be scheduled in order to improve equipment utilization and accommodate fluctuations in the demand patterns. Several decisions must be made: the type of campaign considering single product campaign (SPC) versus mixed product campaign (MPC), the transfer policy between stages taking into account zero-wait (ZW), no intermediate storage (NIS) or unlimited intermediate storage (UIS), and, finally, the batches sequencing of different products in order to optimize a suitable objective. This is a very challenging task given the combinatorial nature of scheduling models. Despite significant advances in optimization approaches considering this type of decisions, there are still a number of major challenges and questions that remain unsolved. (Méndez et al., 2006).

Many papers have been published dealing with design and scheduling of flowshop plants, but usually as decoupled problems. Moreover, when both problems have been simultaneously treated, the simplest scheduling policy has been considered, namely SPC with NIS or UIS. This assumption is very limiting from the commercial point of view where a more steady supply of products is required. Birewar and Grossmann (1989) consider that sequencing of batches of different products in mixed product campaign (MPC) can reduce idle times to increase equipment utilization. Their models incorporate MPC in the design of multiproduct batch plants but considering only one unit per processing stage. Mixed Integer Linear Programming (MILP) models for the minimization of cycle time (CT) for UIS and ZW policies were developed, involving sequence-dependent transition times. Later, Birewar and Grossmann (1990) consider the case of MPC with UIS policy taking into account a maximum number of units in parallel in each stage.

Recently, Liu and Karimi (2007, 2008) develop and evaluate a series of slot-based and sequence-based MILP formulations for scheduling flowshop plants with parallel units in each stage and NIS and ZW transfer policies. Given the plant structure (number of parallel units in each stage), the number of batches of each product to be processed in the plant in the available time horizon, and the processing times of batches at stages, the proposed model assigns batches to units and identify the times at which they should start/end their processing in order to minimize makespan. Each stage is treated as a black box in which batches enter and exit without distinction among the individual units involved. Then, these kinds of formulations cannot be incorporated to the design problem of flowshop plants where the units sizing must be also solved and makespan is not an appropriate objective. Taking into account that long time horizons are used, formulations using campaigns are more adequate and, therefore, the determination of CT must be modeled in order to attain a more appropriate representation.

In this work a detailed, large scale and MILP mathematical model for support simultaneously design and scheduling of flowshop plants, considering ZW transfer policy and MPC, is addressed.

A batch plant with  $N$  stages, that produces  $N_p$  products, and with  $K_j$  available parallel units in stage  $j$ , is considered. Since the parallel units in each stage  $j$  are assumed to be identical, a batch can be processed on any unit with the same processing time. Thus, a unique processing time  $t_{ij}$  is defined for product  $i$  in the stage  $j$ . The assignment of batches to specific units is realized under a synchronous slot-based representation (Méndez et al., 2006).

In order to avoid original non linear design formulations, it is assumed that units are provided in discrete sizes, which is the usual commercial procurement policy, and that a maximum number of batches of product  $i$  ( $NBC_i^{UP}$ ) is allowed in a campaign.

Design constraints pose the production requirements selecting the number of units for each stage with their sizes. Appropriate scheduling constraints are incorporated to obtain the production sequence of different products in a campaign, fulfilling demands in the time horizon. The objective function minimizes the investment cost for the plant configuration. The proposed MILP model is a novel approach where the simultaneous optimization of plant design and scheduling considering MPC can be solved to global optimality with reasonable computational effort. The performance is assessed taking into account the main problem parameters.

## References

- A. P. Barbosa-Póvoa, 2007, A critical review on the design and retrofit of batch plants, *Comp. & Chem. Engn.*, 31, 833–855.
- C. Méndez, et al., 2006, State-of-the-art review of optimization methods for short-term scheduling of batch processes, *Comp. & Chem. Engn.*, 30, 913–946.
- D. Birewar and I. Grossmann, 1989, Incorporating scheduling in the optimal design of multiproduct batch plants, *Comp. and Chem. Engn.*, 13, 141 – 161.
- D. Birewar and I. Grossmann, 1990, Simultaneous synthesis, sizing, and scheduling of multiproduct batch plants, *Ind. Eng. Chem. Res.*, 29, 2242 – 2251.
- Y. Liu and I. Karimi, 2007, Novel continuous-time formulations for scheduling multi-stage batch plants with identical parallel units, *Comp. & Chem. Engn.*, 31, 1671–1693.
- Y. Liu and I. Karimi, 2008, Scheduling multistage batch plants with parallel units and no interstage storage, *Comp. & Chem. Engn.*, 32, 671–693.